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Intelligent Food Safety and Authentication Platform: A Blockchain-Enabled Machine Learning System for Food Verification

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Abstract- Livestock and agriculture are essential to social and economic stability. Many individuals have serious concerns about food safety and supply chain transparency. Blockchain and the Internet of Things (IoT) are becoming more popular because of their success in a variety of applications. They provide a lot of data, which advanced deep learning (ADL) approaches can effectively use and optimize. From the perspective of supply chain management, these developments are important for a variety of activities, including increased visibility, provenance, digitization, disintermediation, and smart contracts. The safe IoT-blockchain data from Industry 4.0 in the food industry is the subject of this article's investigation. We suggest a hybrid model based on recurrent neural networks (RNN) using ADL approaches. In order to optimize the parameters of the hybrid model, we combined genetic algorithm (GA) optimization with long short-term memory (LSTM) and gated recurrent units (GRU) as prediction models. After using GA to determine the ideal training settings, we cascade LSTM with GRU. We tested the suggested system's performance with varying user counts. In addition to assisting supply chain practitioners in utilizing cutting-edge technologies, this article will assist the industry in formulating regulations that align with ADL's forecasts.

Keywords- internet of things; blockchain; advanced deep learning; industry 4.0; provenance

I. INTRODUCTION

In order to establish a fully linked organisation, Industry 4.0 integrates wireless technologies, sensors, and smart machinery. One important element of Industry 4.0 is the Industrial Internet of Things (IIoT), which gathers data on operations, equipment performance, supply, and orders. It also uses big data to aggregate data from manufacturers, suppliers, and customers. In the current world, food safety is a major concern. To improve the management of the safe production of agricultural goods, including identification and tracking, governments must swiftly develop rules and implement a number of measures. Along with agricultural products, meat products make up a significant portion of human nourishment. The agriculture and livestock industries contribute to addressing the world's rapidly growing hunger needs. Crop yields and meat consumption have generally increased as a result of the green agriculture and livestock revolution.

In addition to wanting to eat, people also want to eat wholesome food. The World Food Program reports that 2 billion people suffer from vitamin and mineral deficiencies, and that malnutrition is the primary cause of death for 45% of children under five [1]. The quality and quantity of food products are being improved by numerous businesses and individuals [2,3,4,5]. In the twenty-first century, research is mostly focused on precision agriculture, which is transforming the agricultural sector by bringing in a number of remarkable technology [6]. Crop yields are being significantly impacted by the rise of information and communications technology (ICT)-based methods; farmers may now use smartphones to remotely monitor farm conditions and operate their equipment. The use of unmanned aerial vehicles (UAV) for identifying weeds and provide real-time data on crop health is greatly appreciated by farmers [7]. ICT has made it easier for us to use water for agriculture and irrigation systems properly. Through online irrigation scheduling and data on the pH of agricultural areas' soil, it provides access to weather reports and information on soil moisture deficit. With the use of farming robots, it enables the production of vineyards of superior quality [8]. Information and communications technologies have an immense impact on the food economy. Blockchain is one such technology that's popular for being visible in the food supply chain.

For Bitcoin, blockchain first became available [9]. The most recent development in economic computing is Bitcoin, which enables users to trade money online quickly, cheaply, and reliably. These days, blockchain is the best way to solve a lot of problems, including logistical [10] and financial [11] ones. In addition to helping to link gadgets and sensors, the Internet of Things (IoT) and blockchain are working together to save time and money, but this method also produces a lot of data. Manufacturers can make better decisions by using advanced deep learning (ADL) techniques to analyse these data [12].

However, the IIoT and smart manufacturing are only used only a limited percentage of food and beverage industry enterprises. Deep reinforcement learning techniques can be used to improve blockchain-enabled IIoT systems [13]. Because blockchain data is cryptographically protected, it aids Industry 4.0 in protecting sensor data [14]. Because of this, blockchain is a reliable and safe platform. The public and private keys belong to each user. A blockchain's message transaction cryptography technique is depicted in Figure 1. The sender encrypts a message using the public key during data transmission, and the recipient with that particular public key can decrypt and read the message.

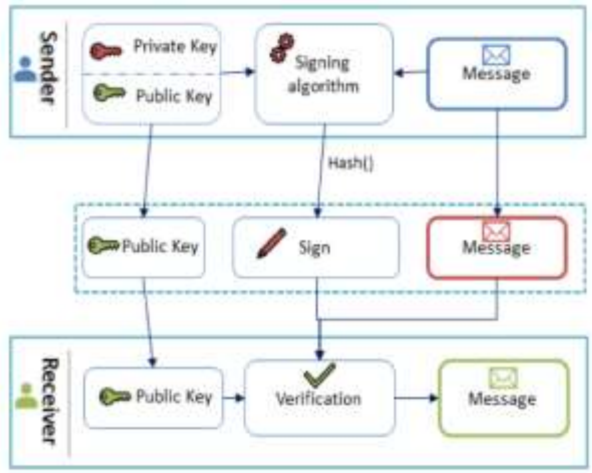

Figure 1. Cryptography scheme for transactions in a blockchain.

If something goes wrong in the production process, artificial intelligence (AI) can be utilised to evaluate data and suggest the next steps. Even recommendations about how to resolve a problem can be mechanised [15]. With AI in the supply chain, we can also monitor our international vendors using natural language processing. AI cuts down on manual labour time, allowing staff members to contribute more significantly to a company. AI enables us to use past data to inform smarter, more educated decisions. When something goes wrong, AI offers crucial warnings and suggestions. It also assists us in keeping an eye on suppliers in other parts of the world to proactively avoid issues.

One of blockchain's most practical uses is tracking a product across the whole supply chain [16]. The distributed ledger of blockchain technology is nearly impossible to alter, making it a perfect instrument for keeping an exhaustive record of ownership transfers that take place across supply chains. The scientific community has been drawn to investigate the potential applications of blockchain technology (BCT) in the supply chain due to its benefits. In addition to strengthening the supply chain and regulating and tracking risk mitigation measures, this technology may also help stop security breaches.

Dairy products like meat, milk, yogurt, butter, and cheese are crucial for fulfilling human nutritional needs. Meat has been a fundamental food source since the dawn of humanity. Due to its high demand, many companies have been found to neglect meat safety, distributing spoiled and rotten products to consumers.

Recently, various scandals involving substituted, stale, and contaminated meat have surfaced globally, including the well-known horsemeat scandal in Britain, tainted meat issues in Brazil, an expired meat scandal in China, and donkey meat incidents in Pakistan. To emphasize the significance of meat traceability, Sander et al. conducted a study exploring different aspects of the meat supply chain, including a survey to assess how Blockchain Technology (BCT) could enhance transparency and traceability in the meat supply chain. The authors aimed to understand consumer perceptions about the use of BCT in supply chain for ensuring traceability and transparency.

IOT and Blockchain in Food Industry

The system for tracing the origin of agricultural products is crucial for ensuring food safety; however, the agricultural supply chain includes a variety of stakeholders who are often spread out geographically, such as the growers of specific products, farmhouses, and numerous sellers. Each entity participating in the agricultural supply chain uses its own data management systems, making it challenging to establish a unified tracking system for information due to the discrepancies in software and data formats.

Table 1 presents a comparison of existing supply chain solutions that leverage IoT or blockchain technology. Lin et al. [23] developed an ecosystem for smart agriculture utilizing both Blockchain Technology (BCT) and the Internet of Things (IoT). In this system, all participants can enter information using their smartphones, and it also autonomously gathers data from IoT devices without needing any human intervention.

To ensure the model's effectiveness, they incorporated the virtual trusted trade BCT Network Cloud Platform as a fundamental component of their architecture. In this model, two categories of transactions take place: the first involves enterprise resource planning, which encompasses information related to trade, logistics, delivery, and warehousing; the second category includes data from IoT devices such as air temperature, air humidity, soil pH, soil nutrients, and ground moisture Prepare.

To ensure the effectiveness of this model, they used the virtual trusted trade BCT Network Cloud Platform as a core of their architecture. According to this model, two types of transactions are performed: one is enterprise resource planning, delivery, warehousing information; and the second includes data from IoT devices, such as the air temperature, air humidity, soil PH, soil nutrition, ground moisture, etc. This model is based on BCT, meaning that all the data communicates through nodes after hashing and digital signatures. Such systems can resolve the food safety issues of the end consumers.

Table 1. Comparison of supply chain solutions. IoT: Internet of Things.

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SR # [Ref]	Year	Blockchain	IoT	Deep Learning	Objective
1 [24]	2018	No	Yes	No	Tracking the environmental stress during the [illegible] products supply chain
2 [25]	2017	No	Yes	Yes	Improving traceability quality using evaluation based protocols.
3 [26]	2018	No	No	Yes	Identification of missing information during the validation process of the supply chain
4 [27]	2018	Yes	No	No	Providing sustainable environment using consortium blockchain for food trading
5 [28]	2018	Yes	No	Yes	A credit evaluation system for accountability in the food supply
6 [29]	2018	Yes	No	No	Using Electronic Product Code Information Services and blockchain for food safety traceability
7 [30]	2018	Yes	Yes	No	Cost effective and user convenient traceability system for perishable food
8 [31]	2020	Yes	No	No	Visualizing food safety risk in the supply chain using a quantitative analysis method
9 [32]	2020	Yes	Yes	No	Creating a value chain from farm to fork using IoT and blockchain.
10 [proposed]		Yes	Yes	Yes	Optimizing provenance system for food with Industry 4.0

In this system, all participants can enter information using their smartphones, and it also autonomously gathers data from IoT devices without needing any human intervention.

IoT and Blockchain technologies (BCT) have the potential to revolutionize the food industry in three key aspects:

- Origin tracking;
- Transaction processing;
- Operational management

Figure 2 highlights the key requirements of IoT and blockchain within the food sector. It outlines the important characteristics of various areas. The provenance area encompasses the supply chain, traceability, and information systems; the payments area emphasizes cryptocurrency, digital transactions, and financial services; while the management area involves digital identity, data analysis, and record maintenance.

Figure 2. Applications of IoT and blockchain in the food industry.

II. PROVENANCE

Tracking the source of food and maintaining complete transparency are essential for ensuring food safety and building consumer confidence. Thanks to BCT, farmers can conduct mobile transactions and access credits, while also benefiting from lower transaction fees. The ability to manage supply chain transactions and financing in real-time could greatly enhance the agricultural and food industries. By utilizing blockchain technology, a more straightforward connection can be created between suppliers and retailers, ensuring that farmers receive equitable compensation for their produce and that retailers can verify the authenticity of their purchases. Digital tokens powered by BCT can be used by small farmers to acquire fertilizer. Because these tokens exist on a blockchain, they cannot be misappropriated or forged, allowing for traceability to ensure that government funds achieve their intended impact. Agriculture integrated with blockchain can offer a wealth of information to consumers. For instance, if a customer purchases a box of cereal from their local store, they can trace its journey from the warehouse all the way back to the farms where the grain was cultivated, and even further to the shop that sold the seeds. They simply need to scan the barcode with their smartphone, which will provide all relevant transaction details, such as when the cereal packet arrived at the market, the farm where the grains were sourced, the precise date and time of production, the farm owner's ID, the identification of the staff member who harvested the crops, information regarding the harvesting equipment, packaging details, and all related environmental conditions throughout the production, processing, logistics, and storage phases. The blockchain network can authenticate all this information autonomously, without the need for human oversight.

Applying blockchain technology (BCT) to agriculture presents a notable challenge due to the complexities involved in automating storage and generating hash data. Xie et al. [35] introduced a storage solution aimed at tracking agricultural products to tackle this issue. They created a secure data storage system for agricultural product tracking utilizing BCT with a dual-chain storage framework. They not only executed the proposal but also developed a functional application to validate its accuracy. In accordance with their suggested system, agricultural products are linked to IoT sensors, which capture data about these products and transmit it to the server in real-time. A dual-chain storage architecture is employed to automatically store the data on the blockchain, while the system also allows for efficient data retrieval for upper application use. The system's design consists of three layers: the application layer, which is utilized for viewing and monitoring the tracking of nodes; the data storage layer, which features a blockchain system built on Ethereum; and the sensing layer, incorporating sensors placed on various devices in different locations. This system employs a dual-chain structure, whereby a parent transaction hash is included in the database; this allows for the retrieval of all identity-related data using only the most recent transaction hash, ensuring that the data remains unaltered. To enhance the storage solution, data filtering is performed within tracking applications. For this purpose, a non-normal data judgment approach has been introduced, and the authors noted through experiments that this scheme offers superior data security compared to non-chain methods; however, the speed of data querying is compromised.

III. PAYMENTS

ICT agricultural systems based on blockchain technology are fixed management systems for records that are localized. Tseng et al. [37] introduced a model for an ICT e-agricultural system that incorporates a blockchain infrastructure, utilizing blockchain technology to store data related to water quality monitoring. This system aids in tracking the amount of water that can lead to optimal yields. The authors also suggested an evaluation tool; this proposed prototype of the ICT e-agriculture framework, developed at National Taiwan University, was employed to monitor irrigation water quality data collected via remote sensors positioned across different farming sites, utilizing the GCOIN blockchain system. GCOIN, a form of private blockchain, was created by a professor at National Taiwan University as part of a project initiated in 2016.

In the agri-food industry, market information is not equally distributed, and there is no assurance of fair market practices. To address these challenges, Mao et al. [27] introduced a food trading mechanism utilizing an alliance chain. The authors employed consortium blockchain technology to create a new framework, which enhances transaction security. Given the various roles, authentications, and permissions required for food transactions within the agri-food supply chain, ensuring secure transactions presents significant difficulties; this technology proves to be advantageous in overcoming these obstacles. Another challenge is enhancing transaction efficiency and helping users identify suitable transactions. To tackle this concern, the improved practical Byzantine fault tolerance (iPBFT) algorithm was developed, and to minimize competition, the authors proposed implementing an online double auction mechanism. The resultant system was named the food trading system with consortium blockchain (FTSCON). Within this system, two types of nodes exist: the user node and the scheduling node. The user node can function as either a buyer or a seller depending on the circumstances. Additionally, scheduling nodes play a role in authorizing and verifying the transaction data within the system. Before a transaction is documented on this blockchain, a consensus process is utilized to validate the data, which is characteristic of a consortium blockchain. This consists of a three-part block that includes the transaction information, consensus mechanism, and smart contract. The architecture of this system is based on Ethereum and incorporates consortium blockchain technology.

IV. MANAGEMENT

Hua et al. [38] developed a platform design aimed at addressing two significant challenges in agricultural traceability systems: the reliability of the data and the complexities in integrating the subsystems of various companies participating in this traceability network. The proposed platform utilizes a distributed peer-to-peer framework to tackle the data reliability issue. Once data enters the distributed network and a consensus is achieved, it becomes immutable. To address the challenge of integrating subsystems, an open data-sharing platform is employed. Nevertheless, this system has a drawback: being a free data-sharing platform means that data is accessible to all stakeholders. However, many companies prefer to keep their data private. To resolve this concern, each stakeholder must select a different licensing agreement. Leng et al. [39] introduced an agricultural supply chain system that employs the public blockchain concept, which is structured on a double chain architecture.According to this concept, the blockchain technology can be either public or private depending on the recording rights of the data. Public blockchains do not guarantee user information privacy and exhibit slower transaction speeds, while private blockchains offer faster transaction processing and consensus. The authors designed a public blockchain specifically for the agricultural sector.

Currently, China represents a significant market for agriculture, needing to sustain 22% of the global population. From China's perspective, Tse et al. [40] performed the first thorough examination of blockchain's role in securing food supply information. In their research, they incorporated theories from multiple scientific disciplines, including IT, management, systems, and empirical methodologies. Their findings indicate that implementing blockchain technology can effectively replace the existing paper-based tracking systems, allowing for a permanent and tamper-proof record of each transaction. They employed a PEST analysis model to evaluate political, economic, societal, and technological factors. The analysis highlights that the government plays a crucial role in ensuring food safety, thus it is essential to cultivate an environment where food supply information systems can thrive, while regulatory bodies must supervise these systems. The societal analysis mentions that consumers increasingly desire more transparency regarding their purchases; therefore, all stages of the food supply chain should be accessible to them. The authors proposed that this system be established in China, necessitating decisive measures to be taken.

While numerous models and frameworks have been put forward for supply chain systems utilizing Blockchain Technology (BCT), no research has approached supply chains from a hazard analysis and critical control points perspective. Tian et al. [41] introduced a traceability system for the food supply chain that integrates BCT and the Internet of Things, focusing on hazard analysis. This study primarily targets risk management and the prevention of food safety issues. The food supply chain is categorized into five stages: the production stage, which requires the evaluation of the crop environment; the processing stage, where the assessment of processing equipment is necessary; the warehousing stage, which relies on the upkeep of cold-chain equipment; the distribution stage, where maintenance of transportation vehicles is essential; and the e-retail stage, which involves evaluating retail management practices based on effective operational procedures. This traceability system operates as a decentralized and distributed model. Various IoT technologies such as RFID, GPS, and wireless sensor networks (WSNs) are employed to gather data. To handle and store this data, Big chain DB is utilized due to its high throughput, minimal latency, and robust query capabilities. This system could play a vital role in restoring consumer confidence in the food industry.

V. SYSTEM MODEL

Numerous entities participate in a food supply chain, which can be grouped into four primary categories: farmers, warehouses, retailers, and consumers. The warehouse itself is divided into two components: the meat processing unit and the distribution segment. Our suggested food supply chain framework aims to leverage cutting-edge technologies including the Internet of Things, blockchain, and artificial intelligence. Figure 3 illustrates the system scenario of the proposed intelligent provenance system that integrates IoT and blockchain technologies.

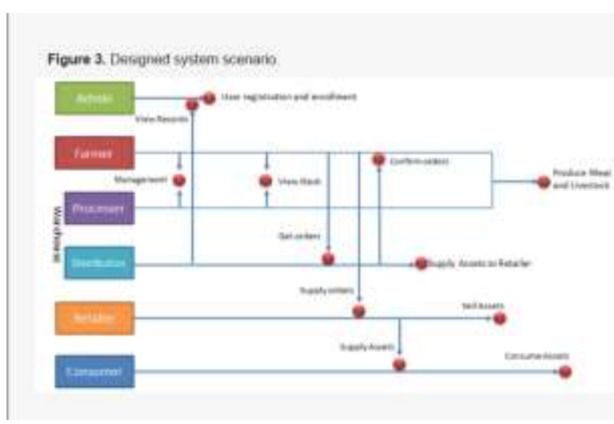


Figure 3. Designed system scenario.

The administrators have the ability to register new participants and access records. Farm owners can manage livestock in coordination with the warehouse. It is the farmer's duty to identify each animal using an ear tag that has an electronic label at the farmhouse; they are also responsible for uploading data to the blockchain via their mobile device or computer. The warehouse updates the records concerning the total assets present at the slaughterhouse using the weighing platform, attaches a hook label to raw meat during the slaughtering process, and transfers various types of data to the blockchain. During the processing of divided meat, each portion of the split meat is distinctly marked using barcode technology, and a related information tracking system is developed to document the production process of the divided meat. All types of data are compiled into the blockchain server. The warehouse is divided into two main sections: processing and distribution. The processing section handles the cutting and packaging of meat, while the distribution section manages the delivery of assets to the retailer. For live animals, the farmer can directly supply the animal to the retailer. The final and one of the most crucial components of the system is the end consumer, who purchases assets from the retailer and consumes them. The consumers may include restaurant owners or individual customers. Ultimately, blockchain technology can be utilized to query meat products through mobile tags or serial numbers, contributing to the establishment of a comprehensive management system for livestock breeding and the production and sale of meat products.

VI. PROPOSED SOLUTION

We have developed an optimized provenance system for the food industry within the framework of Industry 4.0, utilizing IoT and blockchain alongside advanced deep learning techniques. For this approach, we have implemented Hyperledger Fabric as our blockchain solution, offering a user-friendly platform for network management of a private blockchain. The architecture of the intelligent provenance system enabled by IoT and blockchain is illustrated in Figure 4. In our method, we identify farm owners as key participants who can create a profile for each animal regarding meat products. Each farmer is capable of generating personal records and duty logs for different segments. They can also employ smart contracts and event notifications to set upper and lower thresholds for inventory data. The processing unit in the warehouse acts as the second participant; during production and processing, the data associated with the ear tags from the breeding unit are transmitted to this processing unit. This unit is tasked with collecting information about various nodes in the production and processing stages, adhering to management standards and specifications, and uniquely identifying products using barcodes. Subsequently, the data are relayed to the distribution unit, which is responsible for delivering goods to retailers. During transportation, product information is displayed on the pallets or packaging barcodes, compliant with standards detailing the origin, quantity, quality, grade, and other specifications. To fully leverage IoT capabilities, every delivery truck is equipped with temperature sensors and GPS for tracking purposes. Upon reaching the designated retailer or distribution point—whether it is a wholesale market or shopping mall—the labels on the packaging boxes must be scanned and the product information uploaded to the system. A traceability system is established through barcodes within the warehousing and logistics distribution management, covering the entire supply chain from production to processing and storage. In the logistics phase, the goods' details are captured on the labels of pallets or boxes. This barcode system can track various aspects, including location, identity, storage and transportation history, destination, expiration date, as well as other pertinent details about the boxes and even individual items. By providing comprehensive data about the goods within the supply chain, the barcode system forges a physical link between products and their complete identity. Users can access this reliable data effortlessly, and the efficient data collection capabilities of the barcode system enable timely feedback of warehouse logistics information to the production and processing stages for guidance. At the point of sale, it is essential to inform end consumers about the origin of the meat products; thus, retail labels on packaged meats must contain human-readable details, while non-packaged meats should present relevant information through alternative means.

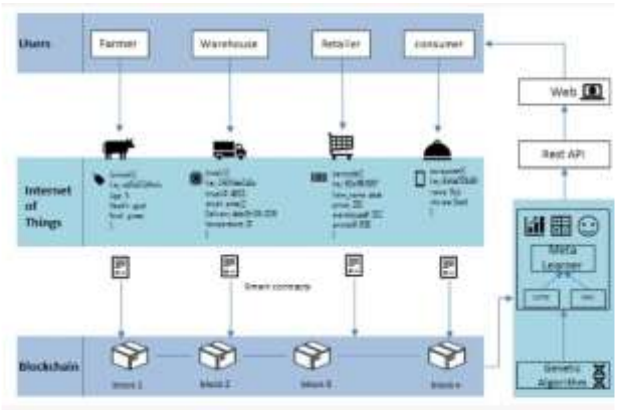
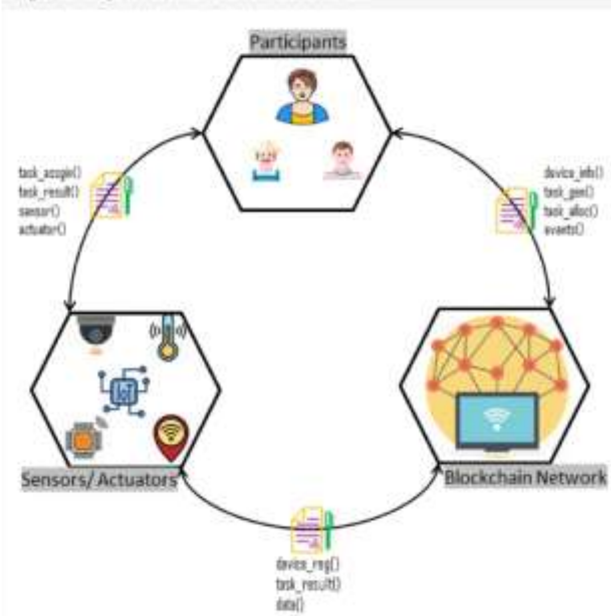


Figure4. IoT–blockchain-enabled intelligent provenance system.

Integration of IoT with Blockchain

The objective of the Internet of Things (IoT) is to turn traditional devices into smart, self-operating ones. Blockchain has surfaced as an essential technology that will revolutionize the way we share data.

Figure 8. Integration scenarios of IoT with blockchain



The ability to establish trust in decentralized environments without relying on authorities represents a technological breakthrough that could transform numerous sectors, including IoT. Merging IoT with blockchain in the food supply chain can help automate processes and reduce time consumption. Figure 8 illustrates the various scenarios of integrating IoT with blockchain and the interactions among participants involved.

Genetic Algorithm

The Genetic Algorithm is a heuristic search and optimization method based on the natural selection process. GAs are widely used for the optimization problem of finding approximate optimal solutions in ample parameter space [48]. The Genetic Algorithm has been widely used as the optimal parameter search technique. Wang et al. [49] used Genetic Algorithms for the modeling of power amplifier behaviors and to improve the hyperparameters of two-layer neural networks. They offered the GAs the input of hyperparameters in binary form, and the GAs treat these binary numbers as genes and train them to approach the optimal solution.

Our issue falls under the category of metaheuristics problems, for which we considered genetic algorithms (GA), particle swarm optimization (PSO), and various other evolutionary methods. Although the performance difference between PSO and GA was minimal, GA demonstrated slightly superior speed [50]; thus, we opted for GA to optimize the hyperparameters. GA imitates the process of species evolution and is based on biologically inspired operations such as crossover, mutation, and selection. The functioning of GA is analogous to natural evolution, which is typically a slow and gradual process, making small incremental adjustments to the solution to discover the optimal outcome. The population processed by GA consists of multiple solutions. Each solution is referred to as an individual, with every individual being represented by a chromosome. The chromosome encompasses a set of parameters that characterize the individual, with each chromosome containing a series of genes [51].

VII. CONCLUSION

This article presents a refined supply chain provenance system tailored for Industry 4.0 within the food industry, utilizing cutting-edge technologies like IoT, blockchain, and sophisticated deep learning. It enables end-users to authenticate their food before consumption, allowing them to trace the source and supply chain of the food they consume. By leveraging advanced deep learning, participants can enhance their operations by predicting future food demand trends and managing their assets through the provided immutable private ledger. Each transaction recorded on this ledger is both timestamped and encrypted, while IoT-enabled warehouses, supply trucks, and retail stores ensure that products are maintained at the correct temperatures. We have outlined the system's model and architecture in our proposal. Ultimately, we assessed the performance of the suggested system across various user scales. Our findings show significant improvements with the recommended system. We established three cohorts of 200, 400, and 800 users and monitored the percentile latency, response time, and system resource utilization. We found that our proposed approach is capable of accommodating a substantial number of users without compromising the system's performance. In the future, this work could be further developed by exploring more intricate business networks.

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