SmartInsure: Blockchain and CNN Leveraged Secure and Efficient Cattle Insurance

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***Abstract*—Agriculture is one of the significant industries that encompasses various activities including crop cultivation and livestock farming to provide necessary resources to societies. Along with providing necessary resources for global stability and sustenance it also serves as the backbone for several countries economies. Agriculture is highly dependent on unpredictable weather and climatic events, making mitigation techniques futile. Due to these uncertainties, many farmers face various hardships when attempting to meet the expected yield and finances. Another major factor influencing livestock farming, especially livestock, is the spread of viral diseases like Bovine Respiratory Disease (BRD) and Foot-and-Mouth Disease (FMD). Livestock insurance is a specific type of insurance within broader agriculture insurance that serves several critical purposes for farmers such as risk mitigation, financial stability, Investment confidence, etc. Currently employed cattle insurance systems are centralized and involve multiple parties exchanging information and payments. These entities include farmers, insurers, veterinarians, and regulatory agencies which are geographically apart and cause significant delays and administrative costs. Hence, a Blockchain and Convolution Neural Network (CNN) leveraged solution SmartInsure is proposed to increase transparency, data integrity, and efficiency, along with a fool-proof way of identifying the insured cattle. The identification of cattle is a major problem in cattle insurance and the lack of a robust identification system can lead to insurance fraud. Hence CNN-based cattle identification using muzzle images can be an effective solution for avoiding such conflicts while processing insurance claims. Considering the cost-effectiveness of the proposed SmartInsure, off-chain distributed data storage is employed for storing muzzle images of insured cattle. Proposed SmartInsure Proof-of-Concept (POC) is designed, and functional analysis is performed to check the business logic implemented. Along with the functional analysis, the efficiency of the CNN model is evaluated for validation accuracy and loss metrics. Results from the analysis show that the cattle are identified with 94.11% validation accuracy and 0.38 validation loss.**

***Keywords*—** Smart Agriculture; Agriculture Cyber-Physical Systems (A-CPS); Agriculture Insurance; Cattle Insurance; Cattle Identity; Blockchain; Convolution Neural Network (CNN)

I. Introduction

Today, cattle farming which is part of the agricultural sector, plays an important role in global stability and sustenance by providing essential resources, such as dairy and meat, to meet the demands of our increasing population. It not only provides the basic nutritional needs of many people but also serves as the backbone for several countries that rely on it for economic growth. Despite its multiple benefits to our world, many farmers continue to face various hardships that hinder their potential to serve this noble purpose. These challenges include the spread of many viral diseases, which harm animal health and jeopardize the financial stability of farmers. In cow farms specifically, common cow diseases include Bovine Respiratory Disease (BRD) and Foot-and-Mouth Disease (FMD). Symptoms of BRD include coughing, lack of appetite, rapid and shallow breathing, and fevers [1], [2]. Similarly, symptoms of FMD include fever, depression, weight loss, appetite loss, and a pause in growth [3], [4]. To prevent the spread of these highly contagious diseases through trade, many safety measures are imposed on farmers, such as quarantine and trade restrictions. However, these measures have considerable repercussions on the farmers themselves. Because they can no longer sell produce, they struggle to make a profit and sustain their farm adequately. In addition, their veterinary and medication expenses may also increase as they attempt to treat their cow's illnesses [5], [6]. The consequences also extend to consumers who rely on these farms. Hence, there should be measures to protect farmers from such instabilities and rescue in case of financial losses.

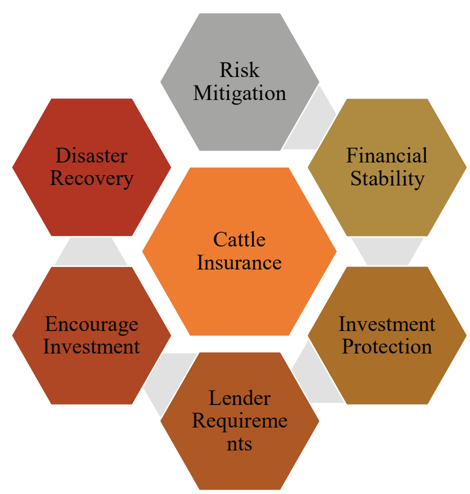

Fig. 1. Significance of Cattle Insurance In Agriculture.

Cattle insurance is one such measure to protect farmers from financial losses associated with their cattle. It is part of agriculture insurance, which supports the farmers in adverse events that harm and result in the loss of cattle, including several types of livestock cows, bulls, calves, etc. This insurance can cover the death of cattle due to unpredictable events, such as illnesses, accidents, and natural disasters like floods, storms, and fires. Cattle insurance, in some cases, also covers the financial losses by farmers in case of thefts and injuries

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during an accident. This financial support from the insurance can help farmers recover from such losses during unpredictable events. Farmers usually invest large amounts of time, effort, and capital into establishing and maintaining the cattle herds. This financial support from insurance can help in recovering some of these expenses and re-invest in the business to improve sustainability. Most commonly, the funds being used in raising the herds are loaned from lenders by farmers. As one of the requirements from lenders, it is mandatory to maintain insurance by the farmers in case of financial loss. Various reasons for the need for cattle insurance are shown in Figure 1.

A typical cattle insurance architecture includes multiple entities that work closely to manage the insurance policies. These stakeholders include cattle owners/farmers who own the cattle and seek to insure their livestock. Insurance companies are responsible for underwriting the policies, setting the premiums, and processing the insurance claims. Insurance agents act as intermediaries who help the farmers with choosing appropriate insurance policies based on their requirements and facilitate the purchase. Some regulatory agencies also participate in the process overlook the operations and ensure the proper regulations are followed and farmers are secured. Inspectors and veterinarians are other important stakeholders who take care of inspecting the cattle before underwriting insurance and while processing insurance claims. In some cases, re-insurance companies also come into play, where the insurance providers insure part of their cattle insurance portfolio to spread the risk and ensure they are covered in case of large losses. Cattle insurance consists of many components, coverage type determines which types of coverage are provided, including death, theft, disability coverage, etc. Next is the premium, which is determined by the insurance providers and many factors like the value of the cattle insured, coverage plan, location, and other risk assessments. Deductible is another component of insurance that cattle owners/farmers need to pay out of pocket in case of filing a claim. Policy terms determine terms and conditions of coverage that include coverage, limitations, and exclusions. A simplified typical architecture for the Insurance Management System (IMS) with different stakeholders and their actions is shown in Fig. 2.

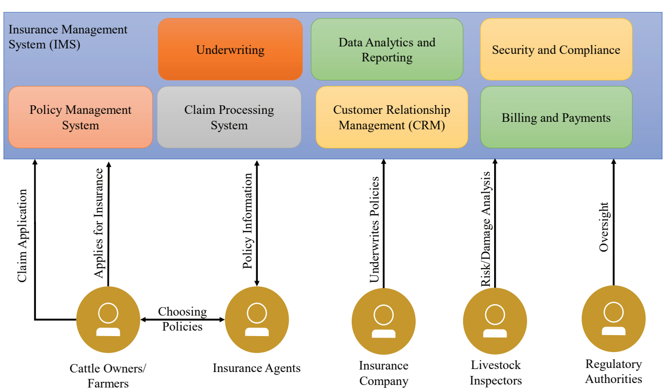

Fig. 2. Typical Insurance Management System Architecture.

The centralized nature of current insurance management systems can lead to significant delays in the processing of claims due to multiple individual actors participating. Centralized systems are also prone to security threats which allow manipulations of recorded data and can result in falsified claims. Blind parties are another problem that can be seen due to centralized architecture, making transactions performed by the stakeholders not transparent. These blind parties also lead to the non-availability of real-time data and delay various processes. Hence, there is a need to improve the current insurance management systems to process claims faster and more efficiently. Blockchain is one of the recent technologies that started as a financial solution to replace the role of intermediary banks to facilitate transactions with a decentralized approach. Later, it showed promising solutions for developing decentralized applications in a trust-less environment. These decentralized applications (DApps) have many features including cryptographic security, transparency, real-time data sharing, removing blind parties in a trust-less environment, etc. This can benefit our discussed cattle insurance systems avoiding all the problems discussed above. Hence, a blockchain-based novel approach is proposed in the current paper with the identity of the cattle determined by the muzzle images.

The rest of the paper is as follows: Section II discusses the novel contributions of the porposed SmartInsure. Section III gives an overview of the prior related research. Section IV describes the architecture of proposed SmartInsure. Section V gives experimental validation and implementation details. Section VI presents the results and analysis. Section VII presents conclusion and future research.

II. Novel Contributions

Below are the problems with current centralized insurance management systems which are addressed in the proposed SmartInsure along with the novel solutions proposed.

A. *Problems with Current Centralized Insurance Management Systems for Cattle*

Some of the problems faced in centralized cattle insurance management systems that are addressed by the proposed SmartInsure are:

- Centralized architectures are more prone to security threats.
- Unauthorized modification of insurance records and falsified claims.
- Significant delay in claim processing affecting the cattle owners/farmers.
- Identification of cattle using RFID tags which can be detached for falsifying information.
- Overhead costs for coordinating distributed stakeholders.
- More prone to disputes due to cumbersome paperwork involved.

B. *Novel Solutions Proposed*

Novel solutions proposed in current SmartInsure are:

- Cryptography-based transaction processing, consensus-based updates, and immutable distributed ledger features of blockchain in proposed SmartInsure help in prevent many of the security threats faced by the centralized architecture.
- The Immutability nature of distributed ledger ensures no modifications can be done to the transactions once they are confirmed.
- Proposed blockchain-based architecture helps create a transparent environment where the real-time data will be available to all the stakeholders, thereby increasing the efficiency of insurance management functions.
- Muzzle images are used to identify the insured cattle, preventing falsified claims.
- Proposed SmartInsure reduces paperwork, which can be cumbersome and lead to many disputes, and overhead costs.

III. Related Prior Research

Blockchain has been explored as a solution in many of the smart agriculture applications including sensing and creating decision support tools for farmers [7], [8], traceability of agricultural foods in supply chain [9], [10] along with managing the agricultural insurance policies. Some of the state-of-art insurance management using blockchain in both agriculture and healthcare are discussed.

A weather index-based crop insurance is proposed in [11] that leveraged NEO platform-based smart contracts linked with Oracle services to trigger the payments based on the magnitude of drought. Another weather index-based crop insurance management that leverages Blockchain and IoT systems to provide reliable data for processing agriculture insurance functions is given in [12]. Similar to this a blockchain-based parametric bushfire insurance proof-of-concept is discussed in [13]. The efficiency of using smart contracts for index insurance products in crops that can be easily adapted by smallholder farmers with payouts triggered by certain pre-defined conditions is discussed in [14]. Not only in agriculture, blockchain has shown promising solutions for managing health insurance. Parametric health insurance, in which payments are triggered with certain medical events, is developed in [15]. In this application, blockchain is combined with IPFS for storing the encrypted policy information and medical events from the network hospitals are monitored. The paper [16] evaluates the efficiency of insurance services through the use of private and public blockchains. Evaluations from this paper determine consortium blockchain as a viable solution in which private blockchain is for settlement of the insurance claims while public blockchain is for insurance payouts. A health insurance blockchain application combined with AI-based fraud detection has been presented in [17].

Data reliability issue while processing insurance claims in livestock is addressed using Blockchain and Internet-of-Things (IoT) in [18]. This proposed system utilizes smart contracts to automate the insurance process. RFID and IoT sensors are utilized to gather reliable real-time data from farms. However, Cattle identity has been a major problem for insurance claims and Radio Frequency Identification (RFID) tags are the most common way of identifying insured cattle. However, this approach can cause insurance fraud as these tags can be easily removed or replaced.

Hence, in the proposed SmartInsure muzzle images are used as fingerprints of insured cattle. Identification of cattle using muzzle has been explored in many of the research. Some of them are discussed in the current section.

The research [19] introduces a cattle face detection model using a two-branch convolution neural network (TB-CNN). With this method, these researchers fuse two different muzzle angles to improve recognition accuracy. Another research using the lightweight CNN model MobiCFNet that provides more cattle identification efficiency in smart livestock precision systems is proposed in [20]. Specifically, this utilizes a two-stage method that enables one-shot cattle recognition. Another deep-learning-based method proposed in [21] implements convolutional neural networks (CNNs) and deep belief neural networks (DBN) for extracting features of the cow muzzle. With this method, the accuracy level was 98.99%. Another study [22] analyzes 59 deep learning models, including convolutional neural networks (CNNs), for identifying cow muzzle images. The results of this data, 98.7% accuracy and fast processing speed of 28.3 ms/image suggest the higher efficiency of using deep learning techniques for cattle identification.

The current proposed SmartInsure takes advantage of both these methods to create an efficient cattle-insurance management system which not only resolves the previously discussed difficulties of centralized IMS but also provides an efficient way of insured cattle recognition in smart agriculture framework.

IV. Architecture Overview of Proposed SmartInsure

An architectural overview of the proposed SmartInsure is shown in Fig. 3. It mainly consists of five components that include Distributed stakeholders, On-chain component, off-chain component, AI-based muzzle image verification, and User Interface. Distributed stakeholders are the participants in the network who collectively work together to establish and manage the cattle insurance policies. These distributed entities include cattle owners/Farmers, Insurance agents, Insurance companies, Livestock inspectors, and Regulatory bodies. The second component is the on-chain component which includes smart contracts on the blockchain platform that holds the entire business logic. Smart contracts designed will have functions for policy management to record policy holder's information, coverage

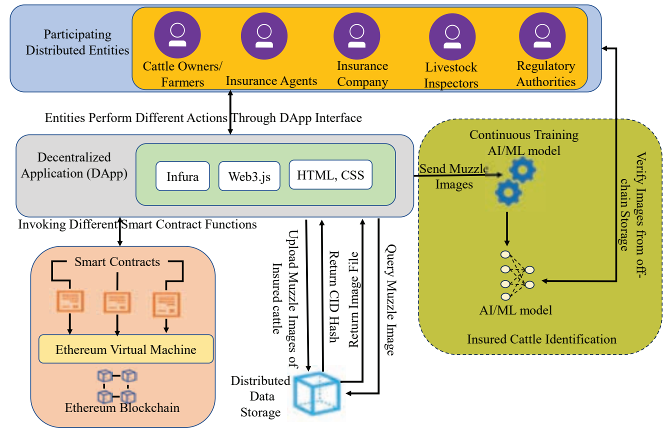

Fig. 3. Architectural Overview of Proposed SmartInsure

terms, set premium amounts and conditions, etc. Different entities will have access to specific functions based on their role, a Role-based Access Control (RBAC) mechanism is implemented using the smart contracts to restrict the actions of the entities. Other insurance-related functions such as policy issuance, and claim submission will also be included in the smart contracts.

An off-chain component is the other component of proposed SmartInsure which contains decentralized file storage systems. As storing the large image files on-chain is expensive, the muzzle image data of the insured cattle is stored off-chain which is cost-effective. AI-based muzzle identification is the next component that consists of an image verification service, AI model, and verification process. A deep learning model is trained on the muzzle images of all the insured cattle and is verified during any of the insurance processes initiated to avoid any falsified claims. The user interface component consists of user-friendly and custom interfaces for different stakeholders to perform assigned actions such as policy underwriting, signing, claim submission, and approvals.

V. Experimental Validation of Proposed SmartInsure

A. Dataset and Exploratory Analysis

Dataset of cattle muzzle images from [23] are used for validation of proposed AI-based verification in SmartInsure. It consists of muzzle images of 268 different feedyard beef cattle totaling 4923 images. Most seen breeds Angus, Angus Hereford Cross, and Continental British Cross are included in the dataset. All the images are taken with a 26MP camera and only clean and cropped images showing the muzzle are included in the dataset. The height and width of all the images in the dataset are 180 pixels. The muzzle pattern with beads and ridges is shown in Figure 4.

B. Implementation

1) Smart Contract Design: Solidity language is used for implementing smart contracts and the Ethereum blockchain platform is used for developing proposed SmartInsure. As there are multiple stakeholders who must perform certain functions based on their roles, a Role-Based Access Control (RBAC) mechanism is employed using smart contracts. For each stakeholder Farmer, Insurance agent, Insurance companies, Inspectors, and Regulatory authorities, separate smart contracts are created that will have functions to add users to roles, verify the user's role, and renounce the roles. These designed modifier functions are attached to insurance operation functions to impose conditional checks of roles.

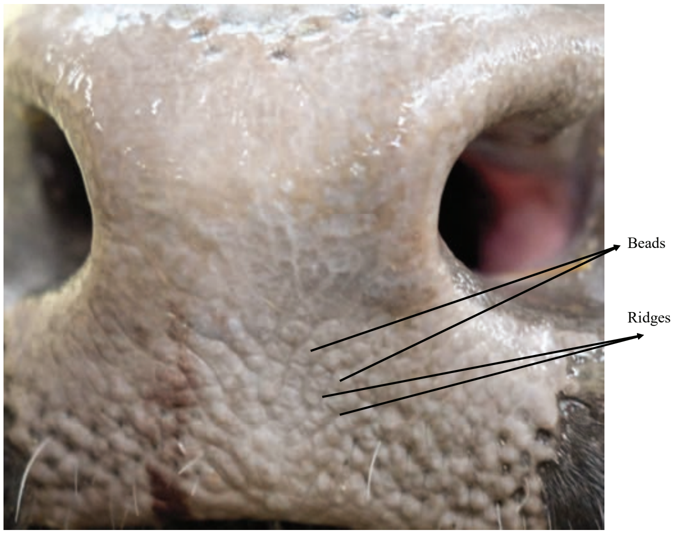

Fig. 4. Muzzle Pattern Showing Ridges and Beads [23].

TABLE I
CNN ARCHITECTURE DETAILS FOR IMPLEMENTED SMARTINSURE

Layer	Type	Filters	Output Shape
1	Rescaling	-	(180, 180, 3)
2	Conv2D	16	(180, 180, 16)
3	MaxPooling2D	-	(90, 90, 16)
4	Conv2D	32	(90, 90, 32)
5	MaxPooling2D	-	(45, 45, 32)
6	Conv2D	64	(45, 45, 64)
7	MaxPooling2D	-	(22, 22, 64)
9	Dense	128	(128,)
10	Dense	268	(268,)

Factory contract design pattern is implemented for creating and managing instances of cattle insurance policy smart contracts. The 'ContractFactory.sol' smart contract will have a dynamic array to store the addresses of deployed child policy contracts 'CattleInsurancePolicy.sol'. A new instance of child contract is deployed whenever the function called 'createContract()' is made from the parent contract. Another function is created to retrieve the deployed child contract addresses. 'CattleInsurancePolicy.sol' has all the information about farmers, and insurance information along with a mapper to store the Content IDs returned from uploading the muzzle images of cattle to off-chain storage. The UML class diagram for designed smart contracts is shown in Fig. 5.

2) Blockchain Network: The proposed SmartInsure is implemented on the Ethereum platform and deployed on the local development environment Ganache. This local development environment provides 10 free accounts each funded with 100 testing ETH. Design of the proposed SmartInsure DApp is carried out by using the truffle development suite which is a development framework for Ethereum that helps in developing, testing, and deploying of DApp. Testing of the DApp is carried out by using the node assertion library Chai.

3) Distributed Data Source: Interplanetary File System (IPFS) is used in the implemented SmartInsure for storing muzzle image files of insured cattle. As discussed, storing large data files on-chain is not cost-effective and leads to high gas costs for each transaction, hence, using off-chain storage is a viable solution. Clients/Farmers to host a network node to perform transactions is not practical. In such cases, the Infura development suite that provides a scalable Application Programming Interface (API) can be used to interact with Ethereum and off-chain storage IPFS.

4) CNN Model Design: CNN model designed for the Muzzle image classification task follows a sequential architecture. The initial layer is a rescaling layer that normalizes the pixel values which helps in preprocessing. Implemented CNN has 3 convolution blocks, each consisting of a convolution layer with relu activation and a Max Pooling layer for down sampling spatial dimensions. The number of filters varies between the blocks and captures various image features. The flattened layer converts the 2-dimensional feature map to a 1-dimensional vector to prepare for a fully connected layer. Two dense layers follow the flattened layer among which the first one has 128 units using relu function, second dense layer with an output size equal to the number of classes. architecture details of the implementation has been shown in Table I.

VI. RESULTS AND DISCUSSION

Functional validation of different DApp functions is tested using the truffle testing module using Chai assertions. These test cases are designed carefully for maximum code coverage to reveal any functional errors. Results of multiple test cases are shown in Figure 6. Functional test results have shown that the implemented logic in the smart contract is executed without any failure. Along with functional testing, an implemented access control mechanism is also tested in which only the addresses with specific roles assigned can perform designated functions. This robust access control mechanism is needed to avoid unauthorized function calls.

The developed deep learning model is evaluated for performance. Validation accuracy and loss are the most used metrics for evaluating the performance of the model. Validation accuracy is the ratio of correctly classified samples to the total number of validation samples. Let the number of validation samples be given as $N_{correct}$ and the total number of samples N_{val}. The Validation Accuracy can be calculated as follows:

$$\text{Validation Accuracy} = \left(\frac{N_{\text{correct}}}{N_{\text{val}}}\right). \tag{1}$$

The result is between 0 and 1 where 0 indicates 0% accuracy whereas 1 indicates 100% accuracy. Computed accuracy during validation and training is shown in Figure 7. From the result the training accuracy reached 99.1% and validation accuracy reached 94.11% with 8 epochs.

Validation loss is the measure for discrepancies between the model predicted values to the actual target values. For validation dataset of size N_{val}, y_{true} representing the true target value, y_{pred} predicted target value and $L(y_{true}, y_{pred})$ is the loss function. Validation loss is computed as using the following expression:

$$ValidationLoss = \left(\frac{\sum_{i=1}^{N_{val}} L(y_{true_i}, y_{pred_i})}{N_{val}}\right). \tag{2}$$

The result is a value greater than or equal to 0, where a value near zero represents the model's predictions closer to the true values. Computed loss for both validation and training is shown in Figure 8. From the result, the training loss is 0.04 and the validation loss is 0.38 with 8 epochs. Evaluated performance metrics of implemented CNN have shown high validation accuracy and low loss. Hence, the method of CNN-based cattle identification with muzzle images is a reliable way as an alternative to physical RFID tags. More accuracy can be achieved by exploring more advanced deep-learning models. Comparative analysis is performed with state-of-art and the proposed SmartInsure solution. As seen from the comparison analysis from Table II, the proposed SmartInsure is the only solution which is taking advantage of a deep-learning approach to control insurance fraud in cattle insurance.

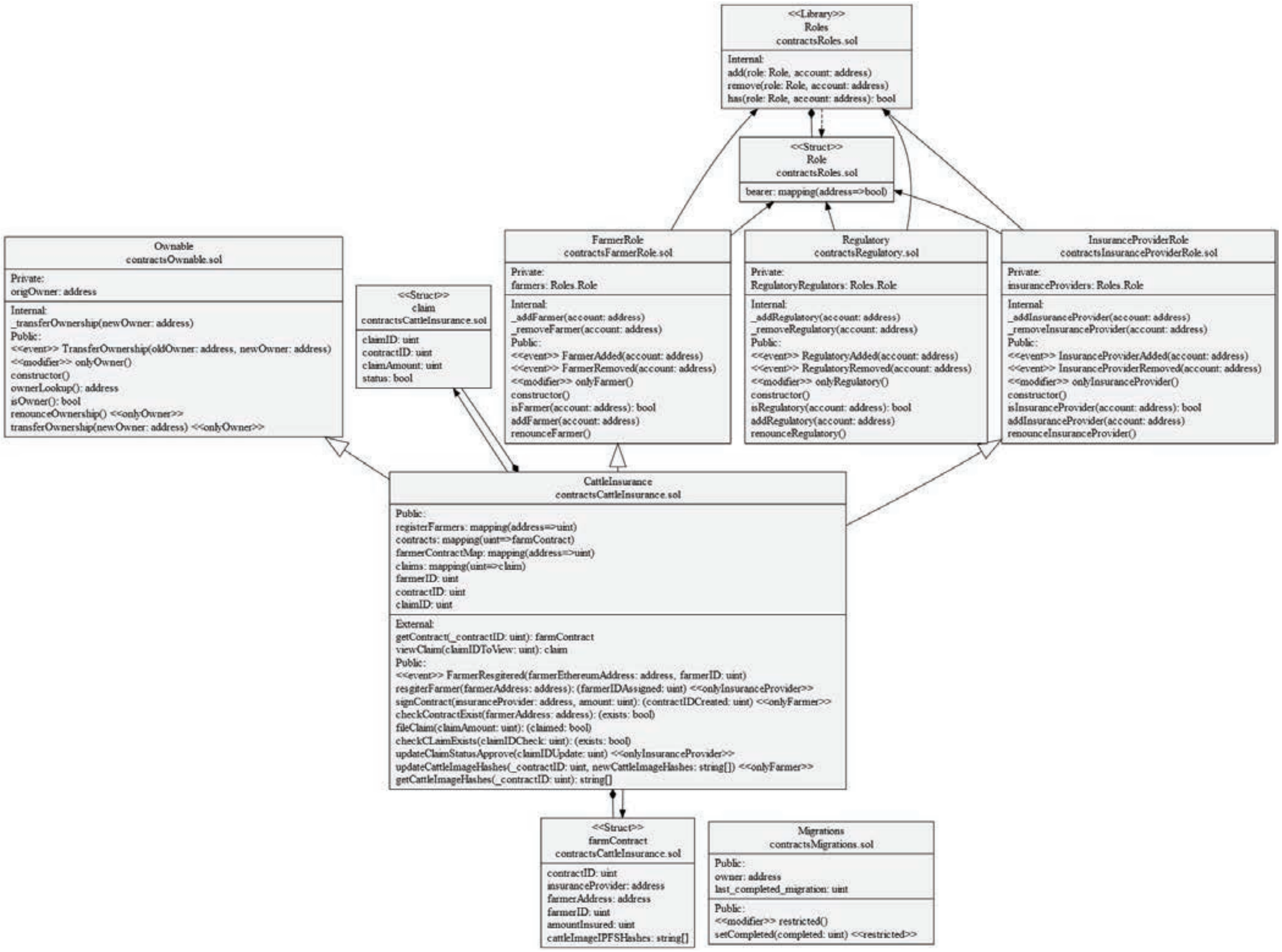

Fig. 5. UML Class Diagram of Designed Smart Contracts for Proposed SmartInsure.

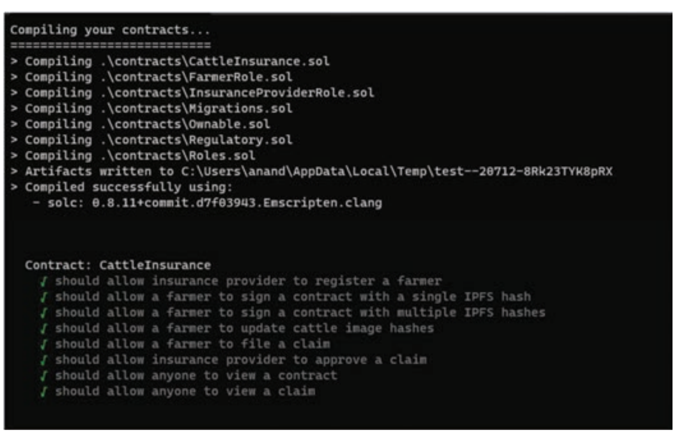

Fig. 6. Functional Testing for Developed DApp of Proposed SmartInsure.

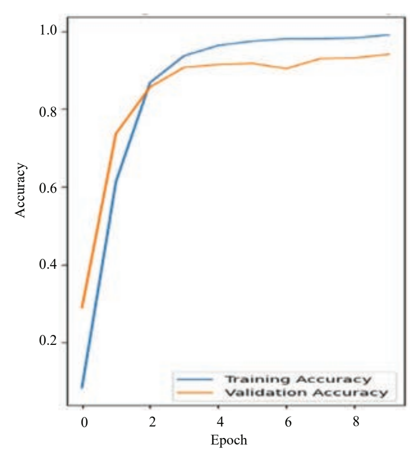

Fig. 7. Training and Validation Accuracy

VII. Conclusion and Future Research

In this work, we have proposed a novel cattle insurance management system SmartInsure, which solves the security and latency issues of typical centralized insurance management systems. Proposed SmartInsure leverages both blockchains to avoid unauthorized modification to the insurance policies thereby preventing falsified claims. Employing blockchain also significantly reduces the claim

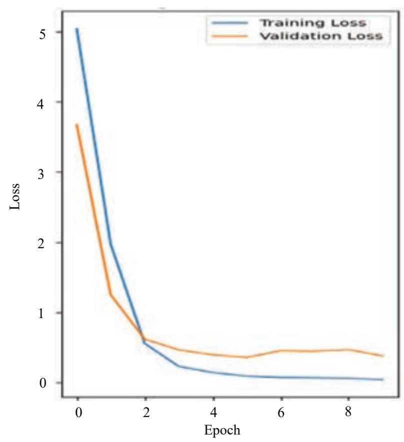

Fig. 8. Training and Validation Loss

TABLE II
COMPARATIVE ANALYSIS OF PROPOSED SMARTINSURE WITH EXISTING SOLUTION

	Shen.et.al. [18]	FarmIns [12]	Proposed SmartInsure
Application	Cattle Insurance Management and Data Reliability	Blockchain and IoT integrated solution for weather index insurance in Agriculture	Cattle Insurance Management with Unique Digital Identity based on Muzzle Images
Cattle Insurance	✓	✗	✓
Unique Identity of Cattle	RFID Tags	-	CNN based Muzzle Identification
Blockchain Platform	-	Ethereum	Ethereum
Off-chain data storage	✗	✓	✓
Handling Large Data	✗	✓	✓

processing time along with avoiding disputes. Cattle identification is another major problem in cattle insurance management as most used RFID tags can be tampered with for falsifying information. A deep learning model approach is presented in the proposed SafeInsure system to avoid false claims. The implemented DApp is tested for all the functions using the truffle test suite and the working of the prototype is verified. The performance of the implemented CNN model is measured using validation accuracy and loss with acceptable values of 94.11% and 0.38.

In future work, more complex interactions between the stakeholders will be explored to include more functionality in the designed SmartInsure DApp. Not only muzzle images but more generic tamper-proof identification techniques will be explored to include different types of cattle. A responsive user-friendly user interface will be designed with multiple views with role-specific functions.

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