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Veterinary Drone: Blockchain-Based System for Cattle Health Monitoring

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Abstract—This work exploits the potential of two important technologies which are UAVs (Unmanned Aerial Vehicles) and blockchain in the context of Agriculture 4.0. We propose a cattle health monitoring system based on UAVs that collect health measures from IoT devices equipping the animals. The main objectives of our system are twofold. First, the consumer will be aware of the quality of his/her food. Second, the national ecosystem (e.g. agriculture ministry, trade ministry) will get useful information about the quality and the number of cattle that can be put on the market. Thus, smart cattle management strategies could be undertaken afterward. The involved entities in such a system are multiple: the farmer, the veterinaries, the Ministry of Agriculture, etc... We first start by studying the system's security by applying the FMEA risk assessment methodology. Our findings motivate us to integrate blockchain technology to manage the data collected as well as the attribution of the UAVs missions via a marketplace. Thanks to its properties, this technology ensures the transparent tracking of cattle status and fairness in the payment of the UAVs managed by private operators. Finally, we develop a proof of concept using the Sui blockchain platform.

Index Terms—Agriculture 4.0, IoT, UAV, Blockchain, FMEA Risk Assessment, Sui blockchain, PoC

I. INTRODUCTION

Agriculture is one of the first industries in the world. Over time, we have witnessed big technological progress that led to the fourth generation, Agriculture 4.0 [1]. Agriculture 4.0 is emerging in parallel with the so-called "Industry 4.0" [2]. It is a modern concept of farm management that uses smart digital technologies to provide sustainable agriculture and help the different agricultural players make smart decisions. The objective is to increase productivity at a low cost, with minimal environmental impact and a high level of food security [3]. Indeed, there is a growing concern about food safety and quality as we have witnessed cases of contamination caused by animal food [4]. Many cattle health problems can be easily treated if they are detected early. By taking preventive strategies, farmers can minimize financial losses and avoid the spread of illnesses among the cattle [5]. One preventive strategy is to monitor the health of the cattle regularly and record health status information automatically. The advantages of such a system exceed the financial profit of the farmer. In fact, livestock

monitoring can improve the quality of animal products. Also, the animal's health status is the first information to allow the consumers to track the provenance and the quality of their food. On the national level, the monitoring of big farms helps to assess the quality and the quantity of the national meat production and to make efficient management accordingly. In this context, we propose a livestock health monitoring system based on UAVs and blockchain technologies. The whole picture is as follows: a governmental authority wants to track the health status of the cattle that are destined to be sold on the market. This will protect the consumer by guaranteeing the meat quality. Indeed, a cattle owner might hide his/her cattle disease. The health information could constitute a basis to help make smart livestock management strategies and promote research studies (e.g. what feed should be given to the cattle, would importing some cattle is needed, etc.). That is why, the health status information should be managed in a transparent way between different stakeholders who might have conflicting interests. To do so, we use the blockchain technology. This technology provides a distributed ledger of immutable and timestamped information [6]. It does not only secure the data against tampering and fraud attempts but also preserves the history of the livestock's health status. In case of a food contamination problem, the blockchain data can easily help to track the responsible for this food fraud. Concerning the data origin in our system, it is done by a number of UAVs that are managed by some private operators entrusted by the governmental authority. The animals are equipped with RFID tags to enable their tracking and identification [4]. They are also equipped with sensors to measure data on their vital signs (heart rate, temperature, and respiration rate). UAVs hover around the cattle, read measures from sensors, and launch transactions to share this data with the blockchain network. As drone operations are recorded in the blockchain, this certifies that they accomplish their mission properly so that their operators can be paid accordingly. As a proof of concept, we assume that UAVs have data collected from the cattle and focus on the transactions launched by these UAVs

to the blockchain. We use the Sui blockchain ¹. The rest of the paper is structured as follows: Section 2 outlines the related work. In Section 3, we describe the proposed system. The FMEA risk assessment methodology is elaborated in Section 4. Section 5 argues the usage of blockchain technology is a system. A proof of concept is developed in Section 6. Finally, we conclude the paper and give future directions in Section 7.

II. RELATED WORK

The related work focuses on UAVs and blockchain and their usage in agriculture.

A. Blockchain in Agriculture

Blockchain technology was first introduced for Bitcoin. Recently, it has been integrated into many sectors such as healthcare, voting, and in particular agriculture. It is used in supply chain management like in [6] where it is integrated with deep learning to make accurate predictions.

In [7] authors propose a blockchain-based fish farm platform that provides fish farmers with secure storage for preserving large amounts of agriculture data. Diverse processes of the fish farm are executed automatically by smart contracts to reduce the risk of error or manipulation. In [8], authors propose an intelligent Smart Watering System (SWS) based on blockchain to provide safe channels for data transmission between users (gardeners) and hardware devices. The results show that the proposed system is efficient and secures the watering process of plants.

For surveillance purposes, blockchain technology is used like in [9] where authors propose an IoT-based prevention system to ensure the protection of their crops from animals during all stages of a harvest. In the paper [4], the authors propose a cloud-based livestock monitoring system to improve food safety by collecting data using a subsystem of RFID sensors (movement, moisture, CO₂, etc.). Blockchain technology is adopted to govern access control for multiple groups in the food supply chain. In the reference [10], a Hyperledger Fabric permissioned blockchain is presented to improve scalability, security, and performance issues of livestock. The solution provides distributed data storage with a service for tracking animal diseases and access control.

B. UAVs-based Applications in Agriculture

UAVs have been widely used in many applications such as surveillance, aerial photography, geographical mapping, traffic control, information gathering, and express shipping and delivery. They indeed provide many advantages such as cost reduction, large coverage areas, and ease of deployment [11]. They can be equipped with different sensors and cameras to effectively cover a large area. The authors of [12] showcase the use of UAVs in the dissemination of pesticides and fertilizers in crop fields, which significantly reduces manual labor and workload and provides optimal safety for farmers. The farmer can drive the drone using an Android application and a Bluetooth module. Crop yields can vary significantly

across the field as in general, crops do not grow uniformly in fields. Authors in [13] investigate the use of UAVs to monitor crop cover and assessing crop growth conditions in real time. This will help to design appropriate management strategies to improve the yield. In addition, drones can significantly contribute to monitoring, detecting, counting, and tracking the animals, searching for grazing lands, and reporting any abnormal situation to the farmer to safeguard herds from potential threats [14].

C. Blockchain in UAVs-based Applications

Recent research studies have integrated blockchain technology and drones in different scenarios. For instance, [15] investigated the opportunities offered by the integration of UAVs and blockchain in the agricultural sector by reviewing recent research projects. [16] is one of the first studies that investigates the integration of blockchain technology with robotic swarm. It explains how blockchain technology can provide innovative solutions to four emerging research concerns: new models of security, decision making, behavioral differentiation, and enterprise for swarm robotic systems. These concerns are described with illustrative scenarios and examples. For instance, authors in [17] present a blockchain-based multi-UAV surveillance framework. This framework allows the coordination of UAVs and the financial exchange between users of the system. Blockchain and UAVs are used for search and rescue missions as in [18], where authors propose an architecture including small and big drones and edge computing to support computation offloading in order to extend the operating time of drones. The blockchain stores drone information, including multimedia data, location, power, and metadata.

III. PROPOSED SYSTEM

Monitoring the cattle health is important as it prevents the spread of the eventual cattle disease. Also, some farmers do not necessarily follow the right cattle vaccination schedule and thus sick cattle could be sold on the market for human consumption. To avoid this, we propose a solution for livestock

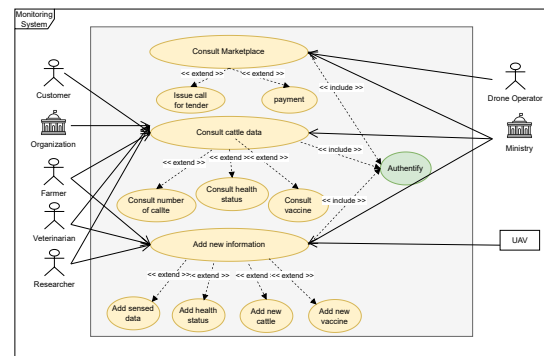


Fig. 1. General use case diagram

health monitoring ensured by UAVs. The main objectives are: (i) on the consumer level: improve food quality and avoid

¹<https://sui.io>

TABLE I
RESULTS OF APPLYING THE FMEA METHODOLOGY TO OUR CATTLE HEALTH MONITORING SYSTEM

Actor	Risk	Severity	Occurrence	Detectability	RPN	rank
Consumer	Risk of experiencing contamination cases	10	5	2	100	1
	Risk of experiencing expensive food products	5	7	1	35	8
	Risks related to unhealthy food products	7	6	2	84	4
	Risk of system failure	7	5	1	35	8
Farmer	Risk of sick cattle	9	5	1	45	7
	Risk of system failure	7	5	1	35	8
Ministry	Risk of economic loss	9	5	2	90	3
	Risks related to making wrong statistics/strategies	9	5	2	90	3
	Risk of experiencing shortage of cattle in the market	7	5	1	35	8
	Risk of system failure	7	5	1	35	8
Researcher	Risk of biased results	8	4	3	96	2
	Risk related to unreliable information	6	5	2	60	5

food contamination, (ii) on the national level: preserve the national livestock health and establish related statistics (e.g to predict the national consumption). Figure 1 illustrates the general use case of such a system. Actors benefit from the system as follows:

- **Consumers** are more and more concerned about the quality of the food they purchase. They can consult our system to know whether a package of meat is healthy by checking its origin, is the cattle vaccinated, what kind of feed did it eat, etc.
- **The farmer** is the most responsible for the welfare of the animals. He/She should follow good practices, good healthy feeding, and make regular vaccinations to his/her cattle. Such information will be registered on our system. Also, the farmer will consult regularly the health status of his/her animals.
- **Veterinarians** have an important role in our system. They are actively involved in the welfare of animals by providing care in a preventive (prevention of disease) or curative (treatment of disease) manner. When a farmer brings his/her animal to the veterinarian, this latter will be able to: consult the previous records about the cattle or update these records with new information like the new vaccines for instance.
- **The government authorities** like the ministry of commerce and the ministry of agriculture can consult or update information about the cattle health (vaccines, cattle number, measures collected by drones, health status) and manage the marketplace.
- **Some organizations** (like consumer protection organization) can benefit from the system by consulting the health status of the livestock.
- **Research labs** can base their studies on the cattle health information data they consult on the system and may add new information (results).
- **Drone operators** use the system as a marketplace where they find new offers and livestock monitoring tenders in which they can participate. The system will enable them to register the work done by the drones that they possess and to be paid accordingly.

IV. RISK ASSESSMENT

A. Overview on the FMEA Risk Assessment Methodology

We want now to assess the risks that our system may encounter regardless the technologies that it uses. One of the most popular methodologies used to evaluate and manage the risks is the Failure Mode and Effects Analysis (FMEA) methodology. FMEA is a technique widely used in the food industry to assess risks in the food production process. This method has also been used to identify the potential of damage or loss of products quality along the agricultural supply chain [19]. There are many variants of the FMEA methodology. However, in a typical variant, the FMEA methodology includes the following steps [20, 21]:

- Step 1: describe the system and its scope.
Step 2: identify the modes of failure i.e the problems that the system may encounter.
Step 3: identify the consequence of each failure.
Step 4: rate the **severity (S)** for each effect, scale it from 1 to 10; (1:low impact on the system; 10: extremely severe).
Step 5: identify the potential root causes for each failure mode.
Step 6: rate the probability of **occurrence (O)** of each root cause (1: not very probable, 10: guaranteed to happen).
Step 7: identify the process controls and indicators that help to identify that the system is encountering a failure.
Step 8: rate the **Detectability (D)** of each failure mode/root cause (1: almost certain to be identified, 10: low probability).
Step 9: estimate the **Risk Priority Number (RPN):** $RPN = S * O * D$.
Step 10: list the risks in descending order and define a strategy of each group of risks.

B. Application of the FMEA Methodology to our System

In this section, we apply the FMEA methodology to our system.

The main potential failure causes of our system are:

- 1) The drones or the sensors fail because of the weather conditions for instance.
- 2) The data, that is the health status of the cattle, is falsified. For instance, the farmer has an interest in introducing an excellent, even wrong, health status about his/her cattle. Also, he/she is likely to show the superiority of

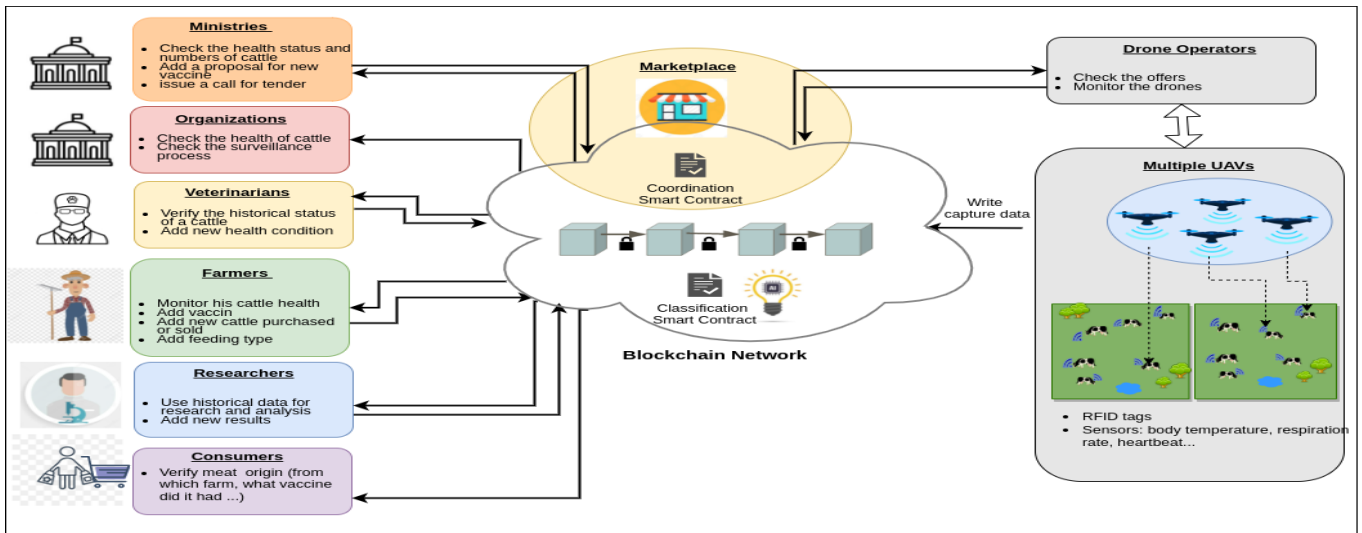


Fig. 2. System overview: Participants, Components, Access Right

his livestock over his neighbors'. Corrupted actors may also falsify data. we can imagine a veterinarian who record wrong information about the cattle for one farmer benefit.

In Table I, we identify the failure modes and rank them according to the computed RPN. From our study, we can identify some security measures. We have to control the data access by defining some rules and/or roles. In addition, maintaining data history with an accurate timestamp and signature improves auditability, non-repudiation and minimizes tampering attempts. Also, information distribution is a means of protecting data as the truth is not owned by one entity. Finally, a regular maintenance of IoT devices is crucial. For our system, we opt for the blockchain technology to manage the data.

V. BLOCKCHAIN AS A SOLUTION

A. Advantages of the Blockchain Usage

The blockchain technology has important features that make it a good candidate for our system. First, there is no central authority. The data is distributed across a peer-to-peer network which ensures data transparency and availability. Second, thanks to the cryptographic procedures it is based on, the blockchain enables data protection. Also, data immutability is an inherent characteristic of blockchain technology. This will avoid data tampering. Third, blockchain ledger maintains data which is signed and timestamped. This allows the easy tracking of information history and guarantees the non-repudiation property. Fourth, the smart contracts can be employed to run automatically the access control algorithms as well as the payment module.

B. Overview and System Workflow

Figure 2 presents an overview of the proposed system. Each drone task starts every day: it collects data from the assigned farm and uploads the collected data to the blockchain network

in real-time. The system workflow is described below in five steps and presented in Figure 3 in a general sequence diagram: **Step1: Assignment of drone mission (Coordination Smart Contract):** This is the object of the first smart contract that focuses on assigning each drone a specific mission: time, farm, period. This module can be seen as an optimization algorithm that aims to maximize the chances of farms to be visited in order to profit from data redundancy while minimizing the cost that the ministry will pay to the drone operators.

Step2: The drone work: Once a drone receives its mission, it hovers to visit the animals, one by one, and to collect data from RFID tags and IoT sensors fixed to each animal. Data collected by the drone is signed, timestamped and sent to the blockchain network.

Step3: Cattle health analysis (Classification Smart Contract): Based on the different measurements taken by the drone, this module aims to decide whether an animal is sick or not. Then, a new transaction with the data collected by the drone and the result of the classification is generated. We intend to develop this classification module as an artificial intelligence model and integrate it within a smart contract. This will help to profit from the automatic execution as well as the immutability and transparency of the code.

Step4: Verification module: It consists in checking that the drone has successfully accomplished its mission and has visited the assigned zone.

Step5: The Drone Payment: according to the accomplished mission, the drone operator is paid by the government authority.

VI. PROOF OF CONCEPT WITH SUI BLOCKCHAIN

A. RFID and IoT sensors

Data collection module is beyond the scope of this paper. However, there are many works that dealt with similar objective. In addition, as a proof of feasibility, we made a state of the art about the appropriate IoT devices. We can conclude that

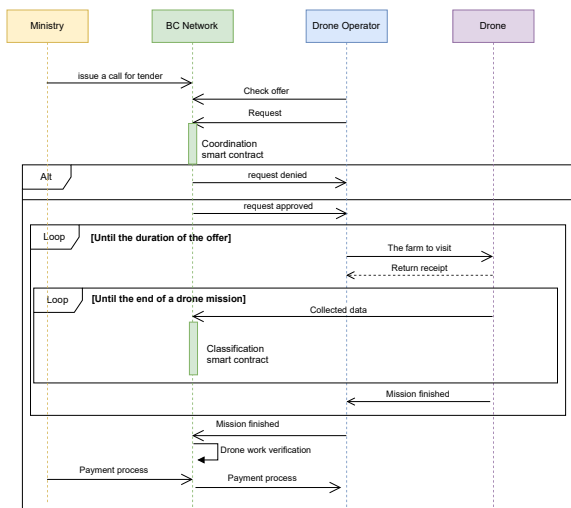


Fig. 3. Sequence diagram

RFID tags are a good candidate to identify and track animals as done in [4]. We also equip these animals with sensors to collect vital measures.

B. Overview about Sui Blockchain

To demonstrate our proposed system, we develop a proof of concept based on the Sui blockchain. The Sui blockchain is a decentralized, permissionless smart contract platform focused on low-latency asset management. It uses a high-performance, quorum-based, fault-tolerant Byzantine consensus with a limited adversary that controls the network up to $f < n/3$, where n is the total number of nodes in the network and f is the number of faulty nodes. Sui is based on [22]: (1) Narwhal: a mempool protocol that ensures the availability of data submitted to the consensus, (2) BullShark: a zero-message overhead consensus protocol, used to agree on a specific ordering of the transactions. Instead of transactions structured in chained blocks, Sui's blockchain is based on a directed acyclic graph (DAG), which ensures fast confirmation and high scalability without compromising security. Transactions are vertices and objects are edges of the DAG. An object may be any type of asset (e.g., a coin, an NFT, livestock, etc.). To develop smart contracts, Sui uses the Move programming language. This language allows the creation of objects with different ownership (owned, shared, immutable). This will be beneficial since owned (independent) objects are executed in *parallel* while shared (dependent) objects are ordered and processed *sequentially*.

C. Setting and Results

We created a local Sui network using a Dell PowerEdge R430 server with an Intel® Xeon® CPU E5-2620 v4 @ 2.10GHz and 32 GB RAM. The network includes a full node, four validators and five user accounts. The full nodes maintain the activities of the blockchain by storing requests for the status and history of the blockchain. This role allows validators to focus on handling transactions. Validators push

transactions to all connected full nodes. We simulated the UAV work as a blockchain user that sends collected data from cattle as independent objects. For each animal, one transaction is generated. Each UAV transaction includes the animal's ID captured from the RFID tag and the temperature and heart rate values collected from sensors equipped in the animals' collars. To evaluate the performance of the Sui blockchain under this scenario, we study the latency achieved for different configurations: different cattle size and different UAV numbers. The latency is defined as the time period required to validate transactions. To obtain our results, we made remote procedure calls (RPC) to the Sui network, and get a real-time event stream. Then we processed this stream using python scripts to get relevant information. In Figure 4, we use one UAV and vary the cattle size which ranges from 100 to 500. As expected, the latency required for validating all transactions increases linearly with the cattle size. This is because the number of transactions to validate increases with the cattle size as well. In Figure 5, we plot the latency when one or two UAVs generate transactions about the same cattle. That is, when 2 UAVs are used, each one generates 100 transactions to monitor a cattle of size 100. We remark that the latency with 2 UAVs is higher than the latency for 1 UAV. However, the latency takes advantages from the simultaneous work of the 2 UAV. Indeed, when we have one UAV, validating a specific number of transactions requires almost the same time for 2 UAVs to validate the double number of transactions. For instance, the latency in the case of 2 UAVs and 200 animals is almost equal to the latency when we have 1 UAV and 400 animals. This is because of the default setting that considers the drone annotation as "owned object", that is transactions invoking these objects are processed in parallel by all nodes.

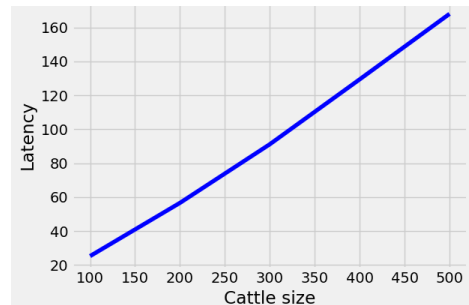


Fig. 4. Latency (in seconds) as a function of the cattle size

VII. CONCLUSION AND FUTURE DIRECTIONS

In this paper, we presented a livestock monitoring system based on UAVs and blockchain technologies. The system collects and shares data between all involved entities transparently and in a secure way. The system integrates a marketplace between drone operators and the ministry of Agriculture. A proof of concept based on Sui blockchain is presented. As future work, we intend to study the behavior of the system in case of network partitioning. We also aim at proposing a consensus algorithm that supports such partitioning.

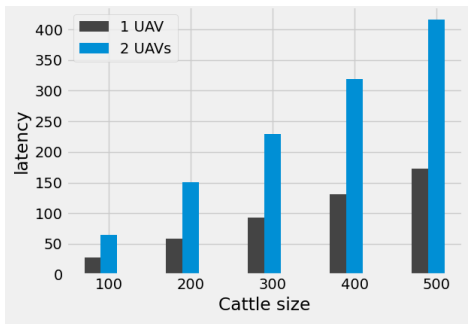


Fig. 5. Latency (in seconds) for different UAVs numbers

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