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Secure and Privacy-Protected Bioinformation Implementation in Air Passenger Transport Based on DLT

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Abstract: Aviation information systems are a key component in ensuring efficient and smooth air transport operations. In this regard, the transfer of passenger information between parties is of paramount importance. With the continuous improvement of biometrics technology, this kind of individual identification that can provide accurate and unforgeable identification is widely used in various fields. This research presents the significance and effective application scenarios of facial recognition in biometrics in air transport operations. Due to the characteristics of aviation information systems, Distributed Ledger Technology (DLT) is used in this study for secure and private transmission of facial recognition information. Distributed systems can give a transparent and secure platform to multiple parties to access sensitive passenger data. This study uses the Corda framework as the DLT that supports CorDapp development. Based on the above techniques, this study proposes two feasible application scenarios. One is a baggage match detection system to prevent misplaced baggage, and the other is an iAPIS system that transmits passenger information in real-time communication between airlines and border control agencies. This article details how to apply the research in these two scenarios, as well as the benefits and implications of the applications. Finally, this article presents an outlook for future development and feasible directions for improvement.

Keywords: aviation information systems; facial recognition; Distributed Ledger Technology (DLT); air transport operations

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1. Introduction

The International Air Transport Association (IATA) has proposed the One ID concept, which aims to offer passengers a consistent, seamless experience across airlines, airports, and governments [1]. According to this concept, the use of bioinformatic identification technology can streamline the user's airport processes, increase operational efficiency, and reduce the need for human intervention. As a product of the fusion of biometrics and information technology, bioinformatic identification technology has demonstrated excellent application potential in a wide range of fields. Its basic principle is to identify and verify the identity of an individual by capturing and analyzing biologically unique physiological or behavioral characteristics. This field encompasses a wide range of biometric traits including, but not limited to, fingerprints, irises, faces, voices, and genetic sequences. Biometrics has important applications in the fields of security, healthcare, finance, and social management, providing highly accurate and unforgeable solutions for individual identification [2]. One of the most popular and technologically mature methods is facial recognition. Since facial recognition is a non-invasive method of bioinformatic identification technology, the person being captured does not need to be in direct contact with the sensor, making it simple and convenient to capture information [3]. For technology collectors, the camera can do the job without special equipment or a collection process. Therefore, facial recognition is applied in this research as a bioinformation recognition method.

Multiple parties participate in air passenger transport, including airlines, airports, and border control authorities. Each of these parties operates at different stages and locations to serve passengers' trips. To ensure the safe and efficient delivery of aviation services and regulations, effective coordination and collaboration among these parties are required. Facial information and other personally identifiable information that needs to be shared by various parties is highly private. The sharing of such information is essential for coordination and cooperation by these relevant participants. While sharing information among a small number of parties in a system may not be complicated, the complexity of managing data privacy and trust among different parties increases as the number of participants grows. Therefore, there is a need for a solution that can facilitate effective information sharing among multiple parties while maintaining data privacy and trust.

Distributed Ledger Technology (DLT) has the potential to address these challenges by providing a secure and transparent platform for data sharing. A DLT system is a type of distributed system that enables independent entities to establish consensus around a shared ledger without relying on a central coordinator [4]. DLT can assist in sharing and synchronizing data across a distributed computer network [5]. Since air passenger transportation involves multiple parties, each group is responsible for different parts of the transportation process. Therefore, DLT with decentralized characteristics is suitable for application in the air passenger information transmission process. Its central control could eliminate single points of failure. In addition, DLT can grant participants different authorizations to distinguish the information obtained and perform different operations by participants, which is called permissioned DLT. Permissioned DLT allows transparent access to data for related parties while ensuring that data are stored securely and accurately using cryptography to prevent access by unauthorized parties [6]. The transparency and security provided by DLT can help manage the accountability of different stakeholders and improve the protection of sensitive passenger data. Based on this, this study adopts DLT as the framework for enabling information sharing and transmission.

The scientific novelty of this research in the aviation service industry is mainly the following:

1. Although digitized biometrics are currently available for applications at each stage of the journey, integrating this digitized information from different stages and achieving meaningful applications remains a challenge. This article proposes a framework that combines the use of biometrics and DLT to improve data sharing between multiple parties in air passenger transport and facilitate passenger operations within airports. The framework enhances coordination and cooperation leading to smoother operations and a better overall travelling experience.
2. The framework, in realizing the vision of One ID, can meet the security requirements of information sharing in the aviation services industry. Its decentralized nature and permission management features ensure data security, preventing unauthorized access and increasing the level of protection of travelers' sensitive data.
3. In addition to the theoretical proposal, this research applies the framework to two possible specific service scenarios to demonstrate how both scenarios can facilitate service expansion and improve operational efficiency through the framework. The first scenario involves solving the baggage mismatch problem and the second scenario involves the sharing of Advance Passenger Information (API) data between airlines and border authorities. These two specific application scenarios validate the effectiveness of introducing biometric identification and DLT technology in improving service and operational efficiency. They demonstrate the feasibility and practical value of these technologies in real-world applications.

The remaining contents of this article are organized as follows. Section 2 describes the related work of facial recognition and information sharing in the aviation transport industry; Section 3 discusses the proposed framework using Corda and facial information identification technology; Section 4 presents a scenario in which this framework can help with the baggage mismatch problem; Section 5 presents another scenario in which this framework can improve API data sharing between airlines and border authorities; and Sections 6 and 7 conclude this article with a discussion of the advantages and conveniences that the bioinformatic identification technology and the DLT framework can bring to both organizations and passengers. It also suggests future research directions for this research and related work that can be improved. The research hopes to provide valuable insights into the potential of DLT in air passenger transport.

2. Related Work

Biometric technology plays an important role in the development of the aviation industry. It is applied to improve the service efficiency and user experience. In 2019, Zhang's study described the application of biometrics including face recognition in airports [7]. José Sánchez et al. also listed the application of diverse face recognition technologies in Automated border control (ABC) systems and explained how the services at airports can be improved in their 2015 study [8]. Khi's 2020 study described the use of face recognition in the border control phase of the aviation service industry [9]. The study also described the role of blockchain technology in protecting information during this process. All of these technologies are mainly focused on a single stage of the aviation service process, rather than the application of biometric information to cover the entire process.

In order to better coordinate the work of the parties in aviation transport services and make them work together more efficiently, how to carry out secure information sharing becomes a worthwhile research issue. Vedaschi's study in 2018 pointed out the importance of information security of shared traveler data [10]. Wu and Wang's study in 2015 protected the security of big data in the aviation industry by using authentication and access authorization [11]. Next, in 2017, Wu et al. proposed a multidimensional encryption scheme for System-Wide Information Management to create a secure information sharing mechanism [12]. However, the study focused on providing encryption for different data formats to provide encryption rather than building encrypted data sharing architecture. Han et al., in their 2017 study, also explained the importance of advanced passenger information (API) and passenger name record (PNR) data sharing among parties in the aviation transport industry [13]. However, this study does not address exactly how the sharing of these data should be achieved on a technical level. Tedeschi and Savio, in their 2019 study, proposed to create an integrated information sharing platform for smart airports using Fog and Multi-Access Edge Computing (FMEC) [14]. This solution allows the integration of information based on high security. This study presented a holistic deployment concept and did not address specific implementation and application scenarios. Poleshkina's research in 2021 proposed a blockchain solution for air cargo [15]. The solution connects the supplier of goods, consignee and customs for secure transfer of information and protocols. Further, this paper only provided the overall architecture, not the detailed implementation and practical applications.

As DLT continues to develop and become more widespread, the aviation industry has begun to explore and adopt this technology to address many of the challenges present in traditional systems. Aberyratne's 2020 book described the positive impacts of blockchain on airlines and airports [16]. He also listed relevant ideas and proposals put forward by various countries and aviation organizations to promote the application of blockchain in the aviation industry. Ahmad et al. in 2021 explored the potential of blockchain technology in the aviation industry and proposed a blockchain-based framework for aviation services [17]. This framework provides a layered description of the blockchain that can support the construction of aviation information systems. Additionally, the study designed a specific implementation framework within a transparent system for revenue sharing for alliance airlines. The authors also summarized the opportunities for applying blockchain technology across different modules of the aviation industry. Yadav et al. in 2022 discussed several applications of blockchain in the aviation industry [18]. Nonetheless, their study provided only a general overview of these cases without detailing the technical implementation aspects. These studies demonstrate the benefits of blockchain for the development of the aviation industry. However, there is a lack of research on the specific implementation of blockchain technology and the application of frameworks in specific scenarios.

3. Framework Architecture

This section describes the technical approach that this article uses to enable the extension of service coverage and enhancement of service efficiency in the two subsequent air transport industry scenarios. The first thing that is explained is the framework for information sharing and transmission. The information system framework proposed in this article for various parties in the air transport industry is implemented based on DLT. Section 3.1 will explain in detail how to build and implement DLT in the air transport industry by using Corda. This article proposes the application of facial recognition technology to improve the service in air passenger transport at present. Section 3.2 states how to implement the facial recognition technology in the DLT framework.

3.1. The DLT Framework

Air passenger transport involves the cooperation of multiple parties, including airlines, airports, ground-handling companies, and government agencies. They interconnect and work together to ensure safe and efficient trips for passengers. During a trip, passengers go through several stages, including booking, check-in, security screening, boarding, and baggage claim. At each stage, data sharing between different parties is required to ensure smooth operations. For example, airlines and airports must share data for coordinating flight schedules, gate assignments and other operational details; and airlines must share API and Passenger Name Records (PNR) with government agencies for border control or security processing.

As DLT is distributed and decentralized, it is suitable for modelling the storage of air passenger transport. This project uses Corda as the DLT development platform [19]. Compared to other platforms such as Hyperledger Fabric, Multichain, or Quorum, Corda has unique advantages [20–22]. It incorporates smart contracts with legal prose, taking into account highly regulated environments. Considering that the participants of this system include government organizations such as border control and that it transmits sensitive private information, this function is crucial for addressing potential legal provisions in the future. Additionally, as a permissioned DLT platform, it enables users to build permissioned networks while creating applications that can solve business problems operating on it. Corda's point-to-point privacy architecture ensures that data are shared only among relevant parties and that all data are kept accurate over its lifecycle. In comparison, Multichain is typically a public blockchain system and is not as strong in terms of privacy as Corda. This system faces high-frequency processing tasks, and Corda offers efficient transaction processing capabilities through point-to-point transactions and a mechanism that does not require full network consensus. On the other hand, Hyperledger Fabric, due to its consensus mechanisms, does not perform as well as Corda under high concurrency. In terms of implementation, platforms like Quorum have weaker compatibility, often requiring additional adaptation and development work. Moreover, Corda has a larger community and wider application.

Application networks are discrete instances of a permissioned collective associated with one or more applications. As Figure 1 shows, these application networks are associated with Corda Distributed Applications (CorDapps). A CorDapp is an application that solves a specific problem using the Corda framework. CorDapps are stored on Corda nodes and executed on the Corda network. Unlike traditional apps which utilize one dedicated system to achieve an assigned task, this structure can distribute apps and allow them to run on multiple systems simultaneously.

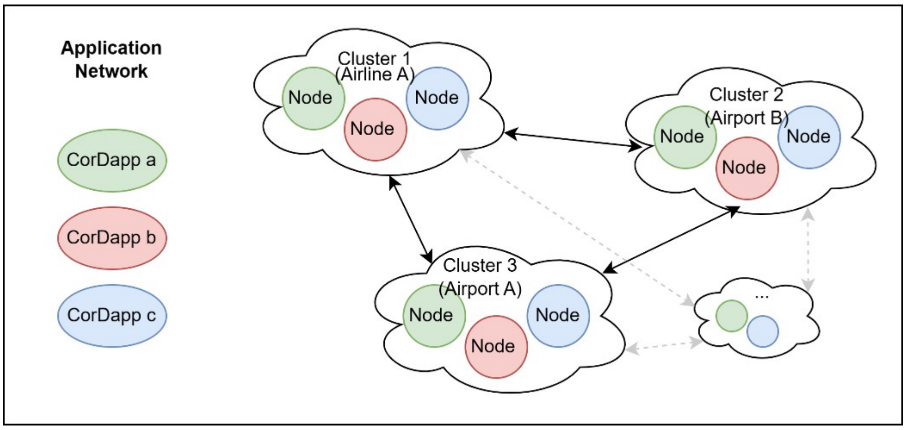

Figure 1. Application network structure.

An application network is composed of nodes, which represent the participants in the network. In order to cope with the large volume of interactions as well as the work requirement, each party in air passenger transport can run a cluster of nodes, with a node or several nodes specialized for one or more CorDapps. Each node in the same Cluster handles different tasks or the same business for different interactions. The node here is associated with a virtual node in the Corda infrastructure, which stores its data, specifically its view of the distributed ledger, in its database vault. Nodes communicate with each other using peer-to-peer communication, which is encrypted using Transport Layer Security (TLS). This allows nodes to send messages directly to each other, without the need for global broadcasts to all nodes on the network [23,24].

A CorDapp is composed of two layers, an orchestration layer for business logic and a consensus layer that defines rules for updating the ledger. There are some basic components of a CorDapp, including Flows, States and Contracts. Flows are discrete pieces of business logic grouped, which define a routine for the node to run, usually to update the ledger. States define the facts that parties use to agree and transact. Contracts define the shared rules for updating the ledger [25]. As shown in Figure 2, nodes with the same CorDapp run on them can interact with each other through the Flow. Each node has its vault for storing data from the ledger that are related to itself. Nodes update the ledger or the system record by proposing transactions, transactions consume States during the updating process. The updates to the ledger are validated by the rules defined in the Contract. Transaction blockchains can be formed when the previous output State is used as input for a new transaction. Based on the blockchain, CorDapps can verify the validity of transaction inputs through the linked transactions.

In addition, the support for RESTful APIs in Corda 5.0 makes it easier for Corda to communicate with external systems and build automated systems. RESTful APIs allow different software applications to communicate with each other and share data in a standardized and structured way. This means that external systems can easily interact with Corda nodes and CorDapps using standard HTTP methods, making it easier to integrate Corda into existing systems and automate processes. Moreover, Corda 5.0 is designed to be cloud-native, which can bring advantages like increased efficiency, reduced cost, and improved availability.

The research utilizes these features and the structure of Corda to achieve secure data sharing among multiple parties in air passenger transport. This article applied this structure to two scenarios to show how it can help improve the current workflow or as an additional solution.

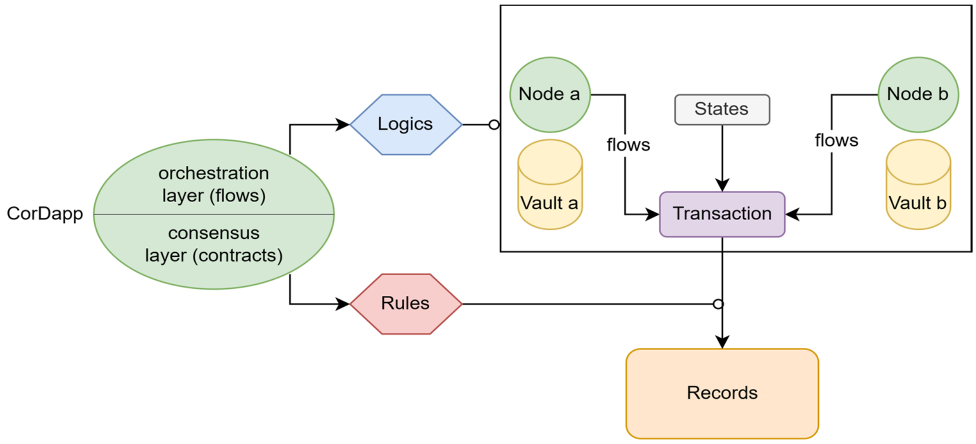

Figure 2. Interactions of nodes based on CorDapp.

3.2. Facial Recognition Technology

Facial recognition verifies or identifies an individual by analyzing and recognizing facial features. Firstly, face image data are captured through the camera. The captured data include various features of the face such as the position, size and relative relationship of the eyes, nose and mouth. In this research, a deep-learning-based facial recognition technique developed in recent years is used for this step and the stored face feature data are put into the DLT framework.

This scheme uses the Convolutional Neural Networks (CNN) model to learn features from image data without manually programming the feature extractor. In the field of facial recognition, CNNs can learn complex patterns of the face through multi-level non-linear processing and effectively deal with changes in posture, lighting and expression. The following is the specific flow of the project implementation.

I. Before training the CNN, a large number of facial images are first collected and preprocessed. The images are resized to a uniform-size square (224 × 224 pixels) at the stage of image normalization. Next, the image colors are normalized in order to reduce the effect of lighting variations. Finally, the diversity of the training data are increased by rotating, scaling and cropping to improve the generalization ability of the model.

II. In this study, CNN models are constructed based on the Inception architecture proposed by Szegedy et al. in 2014 [26]. In facial recognition tasks, this architecture can recognize different facial features through its deep and complex feature extraction capabilities.

Convolutional Layer: the entire image is scanned using multiple small convolutional kernels, these filters are capable of capturing local features of the image such as edges and corner points. By parallelizing multiple convolutional layers employing different convolutional kernels, the model captures information at different scales within the same layer. This design allows the network to learn multiple features in each module, enhancing the model's ability to perceive different parts of the image. The use of 1 × 1 convolutional layers before larger convolutions effectively reduces the depth of the input to the larger convolutional kernel, thereby reducing computational complexity. It could meet the fast recognition speeds required for the use of facial recognition techniques in the airline service industry.

Activation Layer: Use ReLU (Rectified Linear Unit) activation function to increase the non-linear capability of the network and help the network learn more complex patterns.

Pooling Layer: Reduces the spatial size of the feature map, reducing the number of parameters and the amount of computation while maintaining important information.

Fully Connected Layer: At the end of the network, the learned features are transformed into a final output, such as a vector, which represents the high-level features of the face.

III. Finally, the training of the model is completed. This process includes forward propagation, loss calculation, backpropagation, and parameter updating.

The trained deep-learning model extracts a high-dimensional feature vector from each facial image. This vector encodes key information about the face, such as facial structure, key point locations, and texture.

Next, the facial features are to be stored in a database in the form of hash values for fast retrieval and comparison. Based on the task scenario of this research and the practical needs of airline service industry applications, this process requires fast response with low computational cost to shorten the service time and improve passenger satisfaction. Therefore, this scheme adopts LSH (location-sensitive hashing) in this step [27]. It performs hash operations and similarity searches quickly and is well suited for real-time queries. Also, the LSH algorithm is relatively simple, easy to implement and maintain, and does not require a complex training process. This can reduce the operational cost of airports as well as airlines.

This scheme constructs a set of random hash tables of the feature vectors by mapping the feature vectors with these hash tables based on p-stable distributed location-sensitive hashing (pLSH). The feature vectors thus extracted can be converted into more compact hash values by a hash function. The hashing process aims to map the high-dimensional feature space to a low-dimensional space while trying to maintain the relative distance of the original features. This accomplishes the task of storing facial features. This technique provides reliable robustness as well as accurate and efficient recognition performance. It also helps in improving privacy protection as hashes are difficult to reverse restore to the original image data. This provides additional security for sensitive applications like identity verification.

In the verification phase, various scenarios correspond to different tasks. For the scenarios that require verification, the verification part of the DLT compares the previously stored feature information with the feature hash of the current face, and a successful comparison passes the verification. For scenarios that require matching, the facial features to be recognized are put into a database for searching to determine if there is a match and to recognize the identity.

4. Scenario I: Automatic Baggage Mistake Prevention

The first improvement scenario in this article is directed at preventing travelers from picking up the wrong baggage when they claim their luggage. Section 4.1 describes the current state of the baggage claim system and related research on improvements, and points out the problems that still exist. As such, this article proposes a solution using facial recognition in conjunction with RFID in a DLT framework. Section 4.2 describes in detail how the solution is implemented. Improvements in this scenario can effectively enhance the traveler's experience by increasing service efficiency.

4.1. Background

Baggage status data are currently shared between airports in real-time through the Baggage Messaging Service (BMS), which is an automated communication platform that supports real-time messaging and tracking of baggage. It works in conjunction with baggage tracking databases and RFID tags used in some airports for end-to-end tracking. Each baggage is identified by a unique Bag Tag Number (BTN) that is attached to it. IATA Resolution 753 defines the mandatory tracking points supporting the process of successfully delivering bags [28]. According to its implementation guide, it covers the range of how to improve the baggage handling by staff during the whole delivery process. Several tracking points are defined to avoid baggage mishandling at acceptance, load, transfer, and arrival. The arrival tracking point here is to inform passengers that the bag is delivered to the reclaim carousel. However, the service has not yet been extended to automatically help passengers ensure that they take similar-looking luggage from the carousel before exiting.

Many research papers aim to improve baggage processing to further improve the passenger experience. The research of Noel et al. in 2021 utilizes image processing and QR codes to allow passengers to collect their own luggage without misplacement [29]. They also have proposed facial recognition to authenticate luggage. However, the research did not propose a specific and secure framework for transferring facial information between parties. This could result in information leakage to the detriment of passenger privacy. The research of Salman et al. in 2021 uses a combination of the mobile application and RFID to keep track and provide a way for passengers to check their own baggage status [30]. However, the checking is based on passengers' active checks. If passengers do not open their apps when they leave, they may take the wrong suitcases that have similar appearances to their own luggage. In 2021, Madana et al. proposed to substitute boarding passes with BLE tags, which are given to passengers after check-in and should return at the boarding gate [31]. However, this way increases the cost and most of the BLE tag boarding passes can also be achieved by web applications that can run on passengers' mobile phones. In 2016, Shehieb et al. linked user details to the RFID tag that is tagged on baggage, and they used SMS to inform whether the baggage was on a belt or not at the arrival airport [32]. However, they omit the details and complexities of how to handle information sharing. For example, the scanners of the arrival airport, do not define clearly how the airport device and server handle the RFID information checking and comparisons in the airlines' local server or cloud server.

There is insufficient research on automated systems to prevent passengers from taking luggage by mistake. The most avoidance measure at the destination airport is to check the baggage tags that stick on the suitcase manually. According to SITA 2022 Passenger IT Insights report, manual checks are time-consuming and prone to error, and RFID tags can help with the match process [33]. Therefore, in this section, the research proposes to use the bioinformatic identification technology, RFID and DLT to provide a method that detects the baggage mismatch at exits. Since facial recognition is more convenient to obtain and examine than other biometric information such as fingerprints and iris, the research uses facial information as the biometric information in the application.

4.2. Solution

DLT is suitable for helping achieve this improvement as some DLT frameworks can now provide information sharing only among related parties. We depict a general flow of the improved process in Figure 3. As the figure shows, a generated data package containing biological information from self-check-in can be used as a unique identifier for the journey of a passenger. The data package is generated based on the token that is generated through the SHA-256 encryption of flight number, passenger ID, passenger name, timestamp and face ID. SHA-256 can guarantee the confidentiality of data on the basis of being efficiently computed [34]. This can avoid leaking passengers' personal information from unauthorized inquiries. The face ID can then be used for self-bag-dropping service. It is used as a process initiator for a bag-dropping process, the baggage tags with RFID are printed for passengers to stick on their baggage and are automatically combined with the token. This combined information that indicates the baggage ownership is then shared with related airlines and arrival airports through DLT. At the arrival airport, as a simple structure, controlled gates with a facial recognition machine and RFID readers should be set up at exits. After the face is scanned, a baggage-checking process is invoked. The cloud server will check whether the scanned facial information corresponds to the tags that the RFID reader sensed. The returned checking results from the cloud server will decide whether the gate is open or not.

The structure of the CorDapp that helps with the sharing of tokens and RFID combinations is shown in Figure 4. At the time, the passenger doing the self-bag-drop, the flow is invoked by the node of the departure airport to issue a BaggageState, which contains the token of the passenger information, and the RFID tags are stuck on the baggage. The issued BaggageState is verified by the corresponding BaggageContract to ensure its validity. Different from conventional CorDapp, the issue process here does not require to be signed by all three parties but only the departure airport to finalize. The flow includes checks to ensure that the parties specified as participants in the state are the intended parties. In this way, the baggage mistake issue should be alleviated. This structure is flexible for extending to more services. For example, during the pandemic period, the baggage checking process at the gate can also be combined with the vaccine check to ensure public health control in the airport.

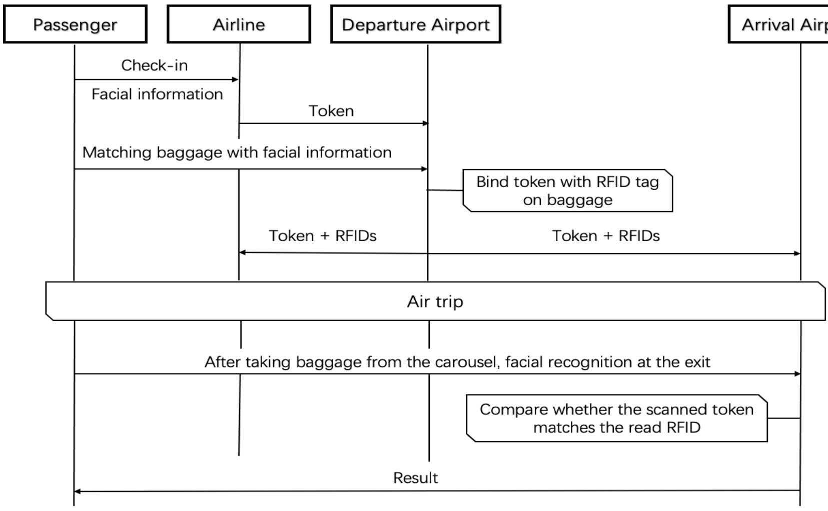

Figure 3. Baggage mismatch avoidance sequence diagram.

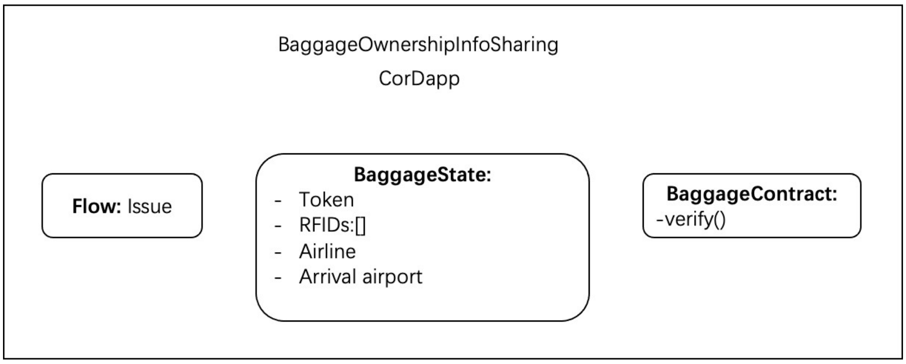

Figure 4. Baggage ownership information sharing CorDapp.

5. Scenario II: iAPIS Based on Corda

The second scenario for improvement is the Advanced Passenger Information System (APIS). This system serves airports, airlines, and border control agencies. Section 5.1 explains why this scenario uses Interactive APIS (iAPIS) of APIS and what can be improved. Section 5.2 describes how facial recognition can be added to iAPIS and how information can be shared through the DLT framework. Improvements in this scenario can increase the efficiency of all three parties and avoid losses of problems such as repatriation in advance.

5.1. Background

APIS is an electronic data interchange system that allows air carriers to transmit travel data to border control agencies. It includes passenger information on the face of a passport like full name, gender, and nationality. APIS can help enhance border security by providing offers with pre-arrival and departure manifest data on all passengers and crew members [35].

The APIS has two different types, non-interactive batch style APIS and interactive APIS. The comparison between them is shown in Table 1.

Table 1. Comparisons of two types of APIS.

APIS Type	Properties
Non-interactive batch style APIS	Description: The complete manifest for all passengers needs to be transmitted before departure at the appointed time.Advantages: - Batch processing of large amounts of passenger information. - Reducing the frequency and system burden of communications. - Disadvantages: - Limited ability to prevent inadmissible persons from boarding.
Interactive APIS (iAPIS)	Description: The API data are transmitted on a per-person basis in real time.Advantages: - Real-time data transmission and greater control over the allowance of passenger boarding. Disadvantages: - More complex to implement.

iAPIS provides passenger information to the destination country's border control agency through a real-time connection, and such real-time communication enables the agency to respond instantly to the carrier based on the results of the vetting process. In contrast, a batch-style API system collects passenger information during the check-in process and then consolidates the information into a single message that is submitted to the destination country's border control agency in a centralized batch process. This can lead to delays and inaccurate information. In summary, the iAPIS system enhances border security by providing pre-arrival and departure manifest data for all passengers and crew members to officers in a more timely and efficient manner.

The conventional iAPIS system transmits personal information in passports and flight information. However, this type of information does not contain the real-time bioinformation of the passengers, which poses a risk of fraud and forgery. In this research, facial information from biometric information is added to iAPIS for information sharing to improve the work efficiency and vetting accuracy of border control agencies.

5.2. Solution

This research uses facial information from bioinformation along with the implementation of DLT to improve the iAPIS system. The improved iAPIS process designed in this research is shown in Figure 5. When a passenger checks in for a flight, the camera at the counter records real-time facial information and saves the corresponding information features according to the technical specifications. At this point, the facial information feature data and other identity information listed in the passport form an identity information packet. The airline sends the field containing the identity information and a field indicating the acceptance status to form the PassengerInfoState to the border control agency of the arriving country and proposes a transaction to consume the state. Since the information is not sent in batches, the border control agency can instantly verify and compare the passenger in the database. The border control agency should use a flow to update the acceptance status field based on the results of the inspection. The earliest time window that can be set is before the end of the check-in process to end and return the feedback. Based on the feedback, the airline can deny boarding passes to non-compliant passengers during the check-in process and conduct a secondary inspection during the boarding process. Passengers board the plane via facial recognition during the boarding process, avoiding the need to double-check documents. At the end of the boarding process, the airline sends an updated list to the relevant parties, such as border control agencies, of all passengers who have boarded the aircraft. The agencies can pre-mark the key persons and process them during border control clearance. All these transactions are recorded in the respective airline and border control agency databases. Transactions belonging to the same flight number and arrival city can be linked in the blockchain to improve traceability.

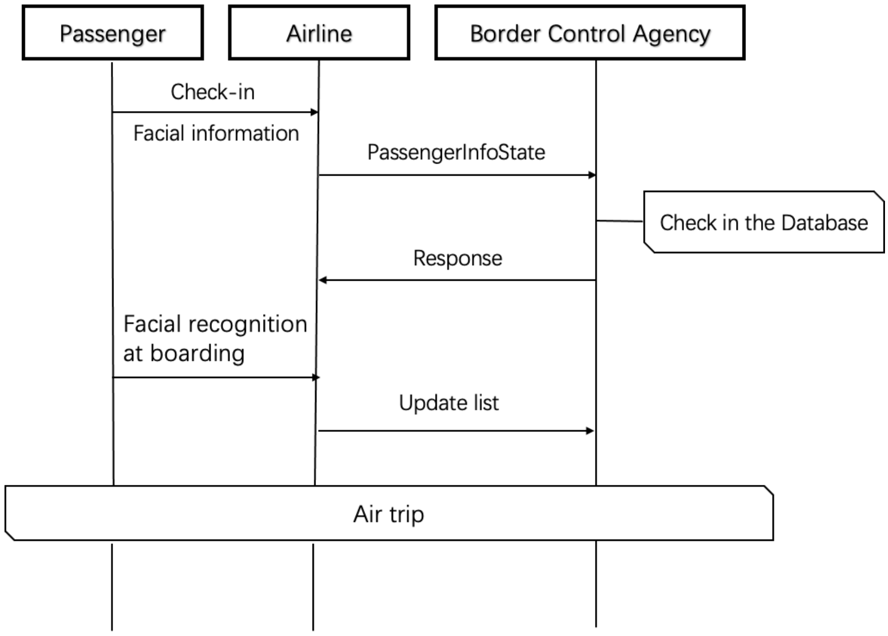

Figure 5. Passenger information sharing sequence diagram.

The structure of the CorDapp, which shares passenger information between airlines and border control agencies, is shown in Figure 6. Passengers enter facial information during the check-in process, the flow is invoked by the node of the airline to issue a PassengerInfoState, which contains all information of passenger. The issued PassengerInfoState is verified by the corresponding InfoContract to ensure its validity, which is the response of border control agencies. Similar to the principle of the previous scenario, this process only requires validation at the board control agencies and confirmation at the airlines. The list sent by the airlines the second time can be processed in a non-interactive batch style since it is only matched at the agency databases and does not need to receive feedback, and the agencies can have enough time to process the data during the flight.

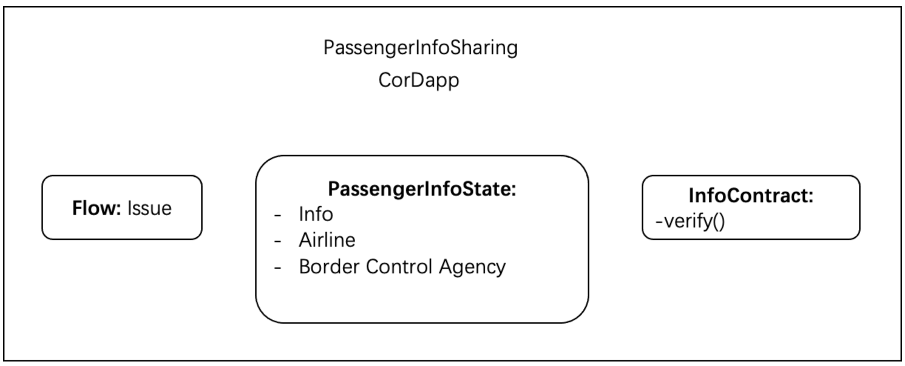

Figure 6. Passenger information sharing CorDapp.

6. Discussion and Future Work

In the first scenario, the advantages of using facial recognition for baggage claim over other methods are clear. Passengers do not need to discreetly hold onto their boarding passes for verification, and the scenario avoid the use of QR codes and other methods that may be inconvenient for the elderly, the young, and the disabled. For these vulnerable groups, the method can be matched with current airline regulations, i.e., the baggage belonging to the actual owner (e.g., a child) can be identified through facial recognition, allowing an assistant (e.g., a parent) to drop off or collect the baggage. Facial recognition is also the easiest to apply and implement instead of other biometric methods. Passengers are also more willing to accept this method than information such as fingerprint or iris. In the second scenario, the facial recognition information has complemented the previous gap in real-time bioinformation. Sending facial recognition information in advance to the border inspection system has a number of practical benefits, with significant advantages for strengthening international border security, increasing inspection efficiency, and improving the passenger experience. Firstly, sending facial recognition information in advance allows for more accurate and efficient identity verification. By capturing travelers' face data in advance, the border inspection system is able to start processing identification before the aircraft lands, thereby reducing the waiting time for travelers at the border checkpoint. This not only improves the efficiency of the entire border clearance process but also reduces the burden on human resources. Secondly, this advance dispatch helps enhance border security. When the aircraft is about to arrive, the system already has the face data of the passengers and can perform identity matching and background checks before the arrival of the passengers. This advanced identity verification measure helps detect potential risks and anomalies in a timely manner and improves the security of international borders. In addition, sending facial recognition information in advance can help improve the traveler experience. By reducing clearance time, travelers are able to complete the border inspection process more quickly and easily, thereby improving the overall travel experience. This is a positive for business travelers, tourists and airlines, helping to promote international tourism and commerce. Taken together, sending facial recognition information in advance to the border inspection system not only improves security and efficiency, but also improves the passenger experience, and is an important step in the overall optimization of international border management. Further, the scenario proposed in this study is also significant in other scenarios. For example, real-time facial information is a secure enough way to verify identity during security checks or boarding checks. Passengers do not need to check their documents again. It brings convenience to travelers.

Two scenarios demonstrate different ways of using facial information. In the first scenario, the facial information is assigned and stored in the passenger baggage information data packet. When the passenger collects luggage, the real-time facial features are compared with the previously stored facial features. The goal is to check whether the information matches consistently between the two times. In the second scenario, the passenger's facial information is sent to the border control agency's database to be matched against the blacklist, a process that involves more searching and matching in the database than in the previous scenario. This involves a different format for storing facial information. There are various data formats for storing facial feature information. This research uses the form of hash values, in addition to which it can also be stored in the form of feature vectors [36,37]. In practical applications, airlines should agree on the storage format in advance with border control agencies to achieve faster matching speed. The study also expects the relevant organizations to introduce unified standards to better serve the air transport industry.

Facial recognition technology is developing rapidly. With the wide application of deep learning, the combination of facial recognition and deep learning has led to a great improvement in the efficiency and accuracy of recognition. In addition to the techniques used in this research, learning a compact feature vector to represent a face could make it more efficient in the storage and comparison stages [38]. As well as high performance on large-scale datasets was achieved by embedding face images into a high-dimensional feature vector [39]. In the future, this study will continue to explore the application of deep learning on facial recognition to implement the technology in more scenarios in the aviation services industry.

This research used the LSH scheme as part of the facial recognition technique; however, this technique still has limitations. Future work will focus on improving the accuracy of

LSH for recognizing minor differences in facial features as well as setting better parameters to achieve stronger performance.

Since different methods and algorithms may be used for storing the hash values of facial features in various border control agency databases, the possibility of developing a standardized matching format for validating the facial features delivered by this framework will be a future research endeavor. This could lead to the integration of digitization of aviation information on a wider scale.

In addition, special attention needs to be paid to the relevant laws and regulations and privacy protection issues. The emergence of new technologies requires improved laws and regulations to accompany them.

7. Conclusions

This article proposes a scheme for applying facial recognition technology in the air transport industry in combination with a DLT architecture as well as specific application scenarios. Through this innovative combination, we can see the great potential for change in the future by applying new technologies in the air service industry. The implementation of facial recognition technology can improve the service level of air transport and provide travelers with a more convenient and secure experience. Compared to traditional identification procedures, this can improve efficiency for travelers and save time costs and resources for airlines and airports. For other relevant organizations such as border control agencies, this technology also complements the necessary information. In order to better share information among related parties, this research applies DLT technology to aviation information systems. Its decentralized nature provides data security and transparency, making the transmission and management of facial feature data more reliable. Such traceable system architecture is a more secure and efficient information management system for the air transport industry. Finally, this article proposes future research and improvement directions so that the technology can be more smoothly applied in practice and provide smarter services for travelers. We expect that with the continuous progress of technology, more and more new technologies can be applied in the aviation industry.

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