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Blockchain-enhanced vehicle data management system with file-based search for crime detection

Chul Jun Sim[1*]
[1]Heasol Co., Ltd, South Korea; spsj1004@gmail.com (C.J.S.).

Abstract: Effective vehicle data management is crucial for traffic safety and public security, requiring both rapid processing and robust security mechanisms. This study presents a hybrid system that combines a file-based search algorithm with blockchain technology to improve performance and security. The file-based search algorithm facilitates quick data retrieval, while blockchain ensures data integrity and protects against tampering. By integrating these two methods, the system overcomes common bottlenecks and security vulnerabilities found in centralized architectures. Experimental results reveal that the proposed system enhances data processing speed by 84%, considerably increasing data security. These findings highlight its practical applications in smart cities, traffic management, and public safety.

Keywords: *Blockchain, Smart contracts, Crime detection, Data integrity, File-based search, Public safety, Smart cities, Traffic management, Vehicle data management.*

1. Introduction

Efficient vehicle data management is vital for traffic safety and crime prevention, but traditional centralized systems are prone to security risks, data integrity concerns, and performance bottlenecks. These systems are vulnerable to hacking and unauthorized modifications owing to their dependence on single storage points [1]. Furthermore, challenges in real-time data processing hinder prompt decision-making.

File-based search algorithms provide quick data retrieval but lack strong security, whereas blockchain ensures data integrity through distributed verification [2]. Smart contracts automate processes, improving system reliability and enhancing crime detection efficiency.

This study presents a hybrid approach that combines file-based search with blockchain technology to optimize both speed and security in vehicle data management. Experimental results demonstrate substantial improvements in data processing and tamper resistance, highlighting its potential for applications in smart cities, traffic control, and public safety.

2. Related Work

Traditional centralized vehicle data management systems are simple to implement but are prone to single points of failure, security vulnerabilities, and performance bottlenecks as they scale. File-based search algorithms enable high-speed retrieval by indexing license plate data into filenames and bitmaps [3]. but their centralized nature makes them vulnerable to tampering. In contrast, blockchain offers a decentralized, tamper-resistant ledger validated by multiple nodes, enhancing data integrity and security [4]. Additionally, smart contracts automate data management and crime detection, further enhancing reliability [5].

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* Correspondence: spsj1004@gmail.com

Table 1.
Comparison of existing approaches.

Approach	Key features and advantages	Average search speed	Security issues
Centralized database	Simple implementation and easy access	Medium (e.g., 50 ms)	Single point of failure, vulnerable to data tampering
File-Based Search	Lightweight, high-speed retrieval	Very Fast (e.g., 4.2 µs)	Limited security, susceptible to unauthorized modifications
Blockchain eechnology	Decentralized storage, integrity assurance via distributed ledger	Moderate (e.g., 35 ms)	High initial setup cost, computational overhead

This study integrates a file-based search for speed and blockchain for security, creating a hybrid approach that optimizes both efficiency and data integrity.

3. System Design

The proposed system combines a file-based search algorithm with blockchain technology to improve vehicle data management and facilitate real-time detection of stolen vehicles. It comprises three main components: blockchain architecture, file-based data management, and smart contracts.

3.1. Blockchain Architecture

The blockchain operates as a permissioned network, granting access only to authorized entities including law enforcement agencies and traffic management organizations. Each node in the network verifies and stores vehicle data, ensuring both data integrity and security. This decentralized design eliminates single points of failure and enhances data protection, making it particularly effective for detecting stolen vehicles [6].

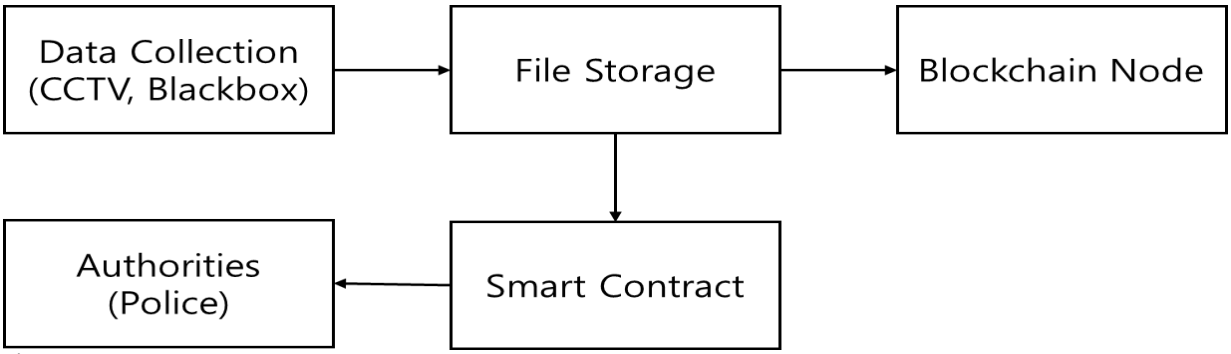

Figure 1.
Blockchain-based vehicle data management structure.

CCTV cameras and black box devices collect vehicle license plate information and send it to the system. Blockchain nodes then store and verify this data, ensuring its immutability and protecting against unauthorized changes. When a detection request is made, these nodes perform a search operation to retrieve the relevant information.

Smart contracts automate the validation of data, check the status of license plates, and trigger alerts when a stolen vehicle is identified. Law enforcement agencies subsequently review the findings and take appropriate action.

3.2. File-Based Data Management

The file-based search algorithm allows for rapid data retrieval by organizing vehicle license plate information in a lightweight file system [2].

The filename generation process derives a unique identifier from the license plate, such as "01GA."

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For instance, "01GA1234" is associated with the filename "01GA," and its status is recorded in a bitmap. A bit value of "1" indicates the vehicle in flagged as a crime vehicle, while "0" signifies a normal vehicle.

To maintain data integrity, the system verifies search results against blockchain records and smart contracts. This streamlined approach enhances search speed and minimizes system resource usage.

3.3. Smart Contract Design

Smart contracts streamline the verification and alert processes by cross-referencing vehicle license plate data with both blockchain and file storage records. This approach secure processing and prevents unauthorized modifications [7].

Once verification is complete, the system assesses the vehicle's status. If it is flagged as a crime vehicle, a smart contract initiates an automated alert, to notify the relevant authorities for immediate action.

4. Algorithms and Implementation

The proposed system incorporates three essential algorithms: vehicle license plate detection, data search, and crime vehicle detection. These algorithms work together, leveraging file-based search and blockchain technology to facilitate rapid and secure vehicle data management.

4.1. Vehicle License Plate Detection Algorithm

The vehicle license plate detection algorithm extracts license plate text from video frames through four essential stages: image preprocessing, license plate area detection, optical character recognition (OCR), and data storage.

In the image preprocessing stage, noise is removed, and edge detection techniques (such as Canny Edge Detection) are applied to accentuate the license plates. Next, the system identifies the regions containing license plates by analyzing edge features. OCR is then used to extract text from these identified areas and convert it into a machine-readable format. Finally, the extracted text is stored in both the file system and the blockchain ensuring data integrity and protection against tampering.

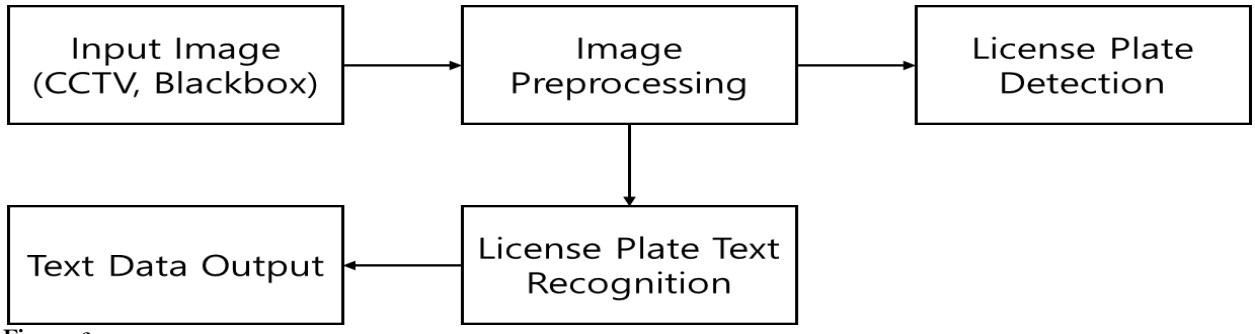

Figure 2.
Vehicle license plate detection algorithm.

4.2. Data Search Algorithm

The data search algorithm obtains a vehicle's status through various methods including file-based lookup, bitmap referencing, blockchain verification, and data synchronization.

In file-based lookup, a vehicle's license plate prefix (such as "01GA") is linked to a specific file for quick access. The system then uses a bitmap structure in that file to assess whether the vehicle is classified as a crime vehicle or a normal one.

Blockchain verification involves cross-referencing the results from the file-based search with records, on the blockchain, thus ensuring data integrity and resistance to tempering. In the event of any

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discrepancies, the blockchain updates the file-based storage to ensure consistency is maintained.

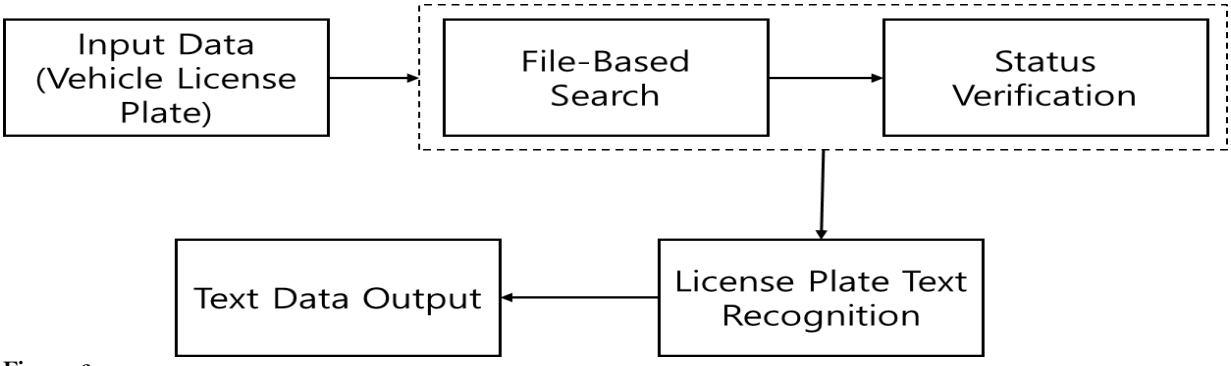

Figure 3.
Data search algorithm.

4.3. Crime Vehicle Detection Algorithm

The crime vehicle detection algorithm verifies vehicle status and generates real-time alerts if a crime vehicle is detected.

The system cross-references the search results with blockchain data to ensure accuracy. If a vehicle's status is flagged as "1" (indicating a crime vehicle), a smart contract is triggered to automatically notify law enforcement.

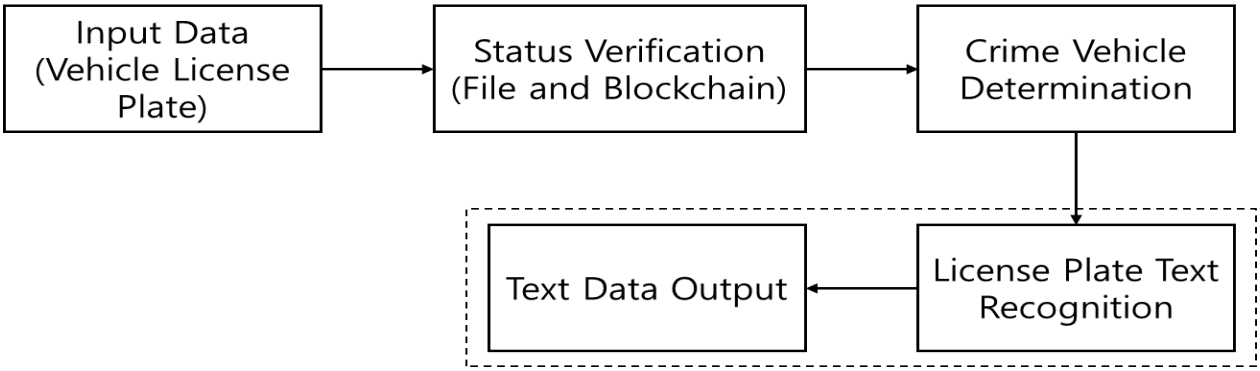

Figure 4.
Crime vehicle detection algorithm.

4.4. Implementation Details

The system improves vehicle data management through three essential components: file-based data processing, blockchain data handling, and smart contract execution.

File-based data processing organizes vehicle license plate information in a bitmap structure, allowing for quick searches based on predefined file naming conventions. Each license plate prefix (e.g., "01GA") corresponds to a specific filename, facilitating efficient data retrieval.

Blockchain data handling ensures data integrity by storing encrypted vehicle status information as hash values. Validation mechanisms cross-check stored data, preventing unauthorized changes and ensuring accuracy. The blockchain's immutable ledger guarantees security and resistance to tampering.

Smart contract execution automates the evaluation of vehicle statuses using Solidity. When a vehicle associated with a crime is identified, the smart contract automatically generates and sends a real-time alert to the appropriate authorities, thereby reducing response times and combining efficiency.

By combining these elements, the system streamlines vehicle data management for real-time urban safety applications.

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5. Performance Evaluation

The system was assessed on the basis of data processing speed, security, and efficiency. A comparative analysis was performed, focusing on centralized systems, file-based searches, and blockchain-based methods.

5.1. Experimental Environment

The evaluation was performed under consistent hardware and software conditions. The system operated on an Intel i5-8250U CPU with 8 GB of RAM, and a 256 GB SSD. For compatibility, the software environment used Ubuntu 20.04 LTS.

The file-based search and processing algorithms were developed in C, while blockchain integration was tested on the Ethereum test network (Ganache). The dataset consisted of 10,000 vehicle records, with 10% categorized as crime vehicles.

5.2. Experimental Setup

Three key metrics-processing speed, security, and efficiency-were evaluated through controlled experiments.

Processing speed was determined by performing 100 randomized searches on a dataset of 10,000 records. Security was assessed by intentionally introducing inconsistencies between the file storage and blockchain records to test integrity verification. Efficiency was measured by monitoring CPU and memory usage during the data processing.

5.3. Experimental Results

The proposed system's performance was evaluated based on three key metrics: data processing speed, security, and efficiency, with the results summarized in Tables 1~3.

- Data Processing Speed

Table 1 shows the average search speed for each system.

Table 1.
Data processing speed

System type	Average search speed
Centralized system	50 ms
File-based search	4,236 ns(4.2 μs)
Blockchain-based system	35 ms

The file-based search method demonstrated the quickest retrieval speed, and the addition of blockchain verification introduced only a slight overhead.

- Security

  The security assessment results are summarized in Table 2.

Table 2.
Security.

Evaluation criteria	Centralized (%)	File-base search (%)	Blockchain-based (%)
Data integrity	70%	85%	99%
Tampering probability	30%	15%	1%

Blockchain offers the highest level of security owing to its distributed ledger and validation mechanisms.

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- Efficiency
  The resource consumption analysis is detailed in Table 3.

Table 3.
Efficiency.

Evaluation criteria	Centralized (%)	File-based search (%)	Blockchain-based (%)
CPU usage	15%	30%	70%
Memory usage	800 MB	400 MB	200 MB

The file-based search consumed fewer system resources, whereas blockchain introduced higher CPU and memory usage.

5.4. Summary and Analysis

The experimental results highlight the benefits and trade-offs of each approach in terms of speed, security, and efficiency. The file-based search algorithm exhibited the fastest data retrieval, making it ideal for real-time applications that demand minimal processing delays. In contrast, the blockchain-based system offered the highest level of security by ensuring data integrity and tamper resistance through its distributed verification mechanisms.

In terms of efficiency, the file-based search algorithm required the fewest computational resources, making it well-suited for environments with limited processing power. However, the blockchain-based system resulted in higher CPU and memory usage owing to its decentralized validation process, balancing performance with enhanced data security.

The results demonstrate that combining file-based search algorithms with blockchain technology effectively enhances both speed and security in vehicle data management. This hybrid approach optimizes performance while ensuring strong data protection, making it ideal for real-time traffic monitoring and crime prevention systems.

6. Conclusion and Future Work

This study presents a hybrid system that integrates file-based search and blockchain to improve vehicle data management efficiency and security. By combining high-speed retrieval with tamper-resistant verification, the system overcomes the limitations of centralized architectures. Experimental results confirm that file-based search achieves nanosecond-level speeds, while blockchain strengthens data integrity and prevents tampering.

The proposed system supports real-time crime detection with minimal latency, providing a scalable and reliable solution for traffic monitoring and public safety. Future research should focus on refining the integration of file-based search and blockchain to optimize computational efficiency without compromising security. Additionally, expanding the use of smart contracts for traffic analysis and fraud detection could further enhance automation in intelligent transportation systems.

Advancements in artificial intelligence (AI) could further enhance predictive analytics, enabling law enforcement to analyze vehicle movement patterns for more effective crime prevention. Integrating this system into smart city infrastructures would optimize real-time traffic flow and improve public safety responses.

To facilitate global adoption, it is crucial to develop standardized protocols for seamless integration with national vehicle databases and law enforcement networks. As blockchain, AI, and smart city technologies continue to evolve, this system has the potential to become a fundamental element of future traffic management and crime detection solutions.

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Transparency:

The author confirms that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

Copyright:

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