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Preliminary Study: RFID-Based Computer Vision Technology Prototype as Information Management Systems in the Logistics Industry

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The author(s) declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Abstract

Purpose: This study aims to fill this gap by evaluating the benefits and challenges of applying CVT to a prototype monitoring camera, as well as developing an optimal implementation strategy.

Research Design and Methodology: Through a mixed-methods approach and black-box testing, the results show that the application of CVT has great potential to revolutionize industrial IMS, particularly in aspects such as real-time monitoring, visual data analysis, and decision-making.

Findings and Discussion: The preliminary results suggest that this technology can improve operational efficiency, accuracy, and safety, thereby enhancing productivity and cost efficiency.

Implications: This research explores the potential contribution of CVT to IMS in the industrial sector, focusing on the use of a prototype Radio Frequency Identification (RFID)-based monitoring camera, and examines its long-term implications.

Introduction

Inventory management plays a crucial role in ensuring smooth and efficient operations within the supply chain and is often a key element that determines a business's success (Gortschacher & Grosinger, 2019). Decision-making in inventory management is generally based on data obtained through automated systems or manual monitoring methods. Manufacturing companies, both large-scale and small and medium-sized enterprises (SMEs), consistently face complex challenges in managing various types of goods, including raw materials, components, finished products, and spare parts (Alam et al., 2017). The smoothness and continuity of material flow along the supply chain are vital factors in ensuring operational success. Responsive actions also contribute to the accuracy of inventory data, which serves as a crucial basis for efficient procurement planning and sales strategies (Astuti, 2022). In line with these challenges, Information Management Systems (IMS) play a strategic role in supporting inventory monitoring through early detection capabilities and effective management of damaged goods. The implementation of inventory monitoring software as part of an IMS system can significantly improve the overall effectiveness of inventory management (Chan et al., 2024).

As technology continues to advance, many innovations now offer a wide range of attractive features tailored for household needs, including enhanced monitoring systems designed to improve home security. Meanwhile, in the warehouse sector, advancements in sensing technology are anticipated to lead to a new generation of sensors that are cost-effective, highly accurate, and capable of broader coverage. To maintain operational efficiency and reliability, companies must be equipped to address various challenges, particularly those related to security, which remains a critical factor in the successful management of business operations (Ekanem et al., 2024).

Technologies such as QR codes and Radio Frequency Identification (RFID) have become commonly used solutions due to their advantages in terms of cost efficiency and ease of implementation (Selvaraj & Anusha, 2021). Computer vision presents a promising solution to the aforementioned challenges. As a rapidly advancing discipline, computer vision focuses on the analysis, enhancement, and high-level interpretation of visual data. Its core objective is to understand the scene captured by a camera and utilize that understanding to control computerized or robotic systems, or to generate enhanced imagery that is either more informative or visually appealing than the original input (Ekanem et al., 2024). This RFID technology enables consistent, rapid, and cost-effective quality assessments while preserving the advantages of non-destructive evaluation and minimizing the risk of significant misclassification. A computer vision system essentially mimics the human eye-to-brain evaluation process, wherein the digital camera functions as the eye and a machine learning algorithm serves as the brain. The camera captures objective and consistent image data, largely free from interfering noise, which is then analyzed by the algorithm to classify or grade it appropriately. With ongoing advancements in both software and hardware, computer vision is increasingly being applied to address complex grading challenges with high precision and efficiency.

This research aims to conduct a preliminary study to support the development of a CVT system specifically designed for monitoring, detecting, classifying, and ensuring the security of goods through the integration of various sensor technologies. This study proposes an innovative and integrated monitoring solution within the IMS framework, designed to monitor the condition of inventory items in a warehousing environment.

Literature Review

Computer Vision Technology (CVT)

Computer Vision Technology (CVT) is a branch of technology that focuses on developing systems that enable machines to "see" and understand the visual environment around them. As computer vision technology continues to advance, it has seen widespread application in agricultural automation, where it plays a crucial role in driving progress within the field (Yuan et al., 2023). This technology enhances human vision by utilizing cameras and computers to identify, track, and measure objects, thereby supporting advanced image analysis processes. As technology advances, CVT has been widely implemented in various sectors, including agriculture automation, where its role has become vital in improving efficiency and productivity (Ekanayake et al., 2021). CVT utilizes cameras and image processing algorithms to analyze and interpret visual data, enabling various tasks that were previously manual to be performed automatically. Through integration with artificial intelligence and machine learning, CVT significantly contributes to improving operational efficiency, data accuracy, and overall information system reliability (Yeung et al., 2019). Current computer vision technologies are capable of overcoming the limitations of traditional monitoring methods by improving efficiency in terms of time, continuity, and cost. This technology offers notable advantages, including low cost, minimal error, high operational efficiency, and strong robustness, enabling dynamic and continuous analysis (Tian et al., 2020).

Information Management Systems (IMS)

The Information Management System (IMS) is a general-purpose database management system and is typically considered a host-language system. Application programs are written by users using an assembler or other procedural languages, and this system is accessed as needed to provide data processing and communication services (Zhang et al., 2022). These systems are essential for supporting decision-making, coordination, analysis, and control by ensuring that accurate, timely, and relevant data are readily available to stakeholders. IMS typically involves several key components, including data collection from various sources, secure data storage, processing of raw data into meaningful information, and the distribution of this information to the appropriate users through accessible interfaces (Veena et al., 2020).

Material Flow

Material flow is a structured process that describes the physical movement of raw materials, components, semi-finished goods, and final products from one point to another in the supply chain (Schandl et al., 2018). This movement starts from the supplier and ends in the hands of the consumer. In its journey, material flow encompasses various important stages, including material receipt, storage, production process, assembly, packaging, and ultimately, delivery or distribution to the final destination. A material flow structure is constructed around a network of flows (also called edges, links, or objects) and processes (also called nodes or vertices) (Markic et al., 2019). Material inflows and outflows must remain balanced within each process, adhering to the principle of mass conservation. When multiple processes are grouped within a defined boundary—forming a system or network—the total mass entering and leaving this boundary must also be equal. Growing concerns about the environmental effects of material systems, along with the limitations of using monetary value to allocate environmental impact, have led to a rising interest in monitoring material flows and evaluating material efficiency (Walz & Guenther, 2021). Understanding the physical flow of materials within supply chains is crucial for addressing issues related to resource extraction and supply security. Although there is growing awareness of the importance of mapping material use in society, progress remains limited. This is primarily due to the lack of transparency in material supply chains and the challenges associated with collecting comprehensive data across various materials and complex processes (Ismail & Hanafiah, 2021).

Radio Frequency Identification (RFID)

Radio Frequency Identification (RFID) is a term used to describe short-range radio technology that facilitates the exchange of digital information between fixed locations and moving objects, or between objects that are both moving (Wang et al., 2018). This technology plays a role in increasing work efficiency and providing convenience in various operational processes. Radio Frequency Identification (RFID) technology, serving as a fundamental component of the Internet of Things (IoT) sensing layer, is now widely utilized across various domains for data integration and management. Its applications span a broad range of fields, including human identification, logistics and retail operations, access control systems, parking management, and indoor localization, among others. (Barlow et al., 2019). Compared to alternatives like barcodes and QR codes, the radio frequency-based identification method offers several distinct advantages. It enables contactless operation, wireless power, non-line-of-sight communication, read and write capabilities, lightweight design, and the ability to read multiple tags simultaneously. These features enable connected "things" to be easily identified and integrated into broader data communication systems. Furthermore, the combination of RFID tags with sensing components enhances functionality by enabling both identification and sensing in a wireless-powered, contactless, and non-line-of-sight manner (Bit et al., 2019).

Black Box Testing

Black box testing is a software testing technique used to evaluate the functionality of an application without examining its internal code structure or implementation details. The primary focus of this method is on the inputs provided to the application and the corresponding expected outputs, ensuring that the system behaves as intended based on its requirements and specifications (Nidhra, 2012). Black box testing, also known as specification-based testing or behavior testing, derives its name from the fact that the tester does not require any knowledge of the application's internal code or implementation. Instead, testing is based solely on the software's specifications and expected behavior, focusing on validating outputs against given inputs.

The two primary techniques for error detection in software testing are Black-Box Testing and White-Box Testing (Kumar et al., 2015). Black Box Testing focuses on evaluating a system's functionality without considering its internal code structure, allowing testers with minimal programming knowledge to perform it. In contrast, White Box Testing requires a solid understanding of the program's internal logic and source code, making it suitable for testers with programming expertise. This method can be applied at any stage after the code has been developed (Guidotti et al., 2019). Black Box and White Box Testing each offer distinct advantages in software testing (Loyola-Gonzalez, 2019). Black Box Testing focuses on validating the system from the customer's perspective, ensuring that it meets user expectations without requiring knowledge of the internal code. Independent testers typically conduct it to minimize developer bias, and it is suitable for individuals without technical expertise. This approach is efficient for large-scale systems. On the other hand, White Box Testing involves a detailed examination of the internal code structure, enabling thorough testing that covers most execution paths. It can be initiated early in the development cycle as it does not depend on the application's user interface and also contributes to code optimization by revealing inefficiencies within the source code.

Both Black Box and White Box Testing also have their limitations (Pirdaus & Hidayana, 2024). In Black Box Testing, redundant test cases may occur if the software developer has already executed similar tests, making it challenging to design effective test cases when requirements are vague or incomplete. This method is also less effective for evaluating complex code structures, and its results can sometimes be overestimated. Conversely, White Box Testing faces challenges related to tool availability, as suitable tools may not exist for all platforms or implementations. Maintaining test scripts becomes difficult when the codebase undergoes frequent changes. Moreover, it is practically impossible to test every possible path or condition in the software, which may result in undetected defects.

Research Design and Methodology

This research employs a mixed-methods approach, which combines quantitative and qualitative methods in the collection, analysis, and integration of data. The mixed-methods approach enables researchers to gain a more comprehensive understanding through a combination of numerical and descriptive data, providing in-depth insights (Taherdoost, 2022). As a basis for conducting research, data were collected from various literature sources, including articles and journals (Almeida, n.d.). The data was then sorted again based on its relevance to the research. The screening results identified a total of 28 literature sources that served as the primary sources for writing, as listed in Figure 1.

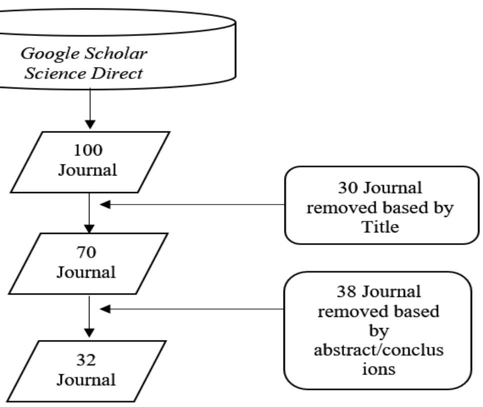

Figure 1. Selection Criteria

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The results obtained from the testing were both quantitative and qualitative in nature. The quantitative data primarily focuses on the number of articles obtained, categorization, criteria for sections, and articles by year, among other aspects. The qualitative data primarily focuses on testing techniques and methods, models, advantages, and case situations, among other aspects. While the qualitative data primarily focuses on testing techniques and methods, models, advantages, and case situations, among other aspects, are also shown. It was found that the software has different aspects, including usability, performance, security, and safety.

Findings and Discussion

Findings

The data processing stages in the RFID software begin with data acquisition through a camera system integrated with sensors, which serve to identify and monitor the condition of goods visually. Once the data is collected, the system performs extraction and recognition of the information contained in the labels, which are then divided into three main subsets: training, validation, and testing data. (Cui et al., 2019). This process is supported by an optimization algorithm that dynamically adjusts the model parameters to minimize the difference between the predicted and actual values. The analyzed and validated data is then presented in a form that can be accessed and utilized by authorized parties for decision-making. (Ullo & Sinha, 2020). This design presents a use case diagram that aims to describe the overall expected functionality of the system. Each use case represents a form of interaction between actors and the system, describing how each actor plays a role in carrying out specific functions. (Oktaviani et al., 2021). The four actors involved have different roles but interact with each other and are integrated in the implementation of the system process. A detailed description of each actor is presented in Table 1, while a complete description of the use cases can be found in Table 2.

Table 1. Definition of actors

Actor	Actor Definition
Administrator	Oversee system configuration, manage user access, and ensure the prototype camera system operates correctly and safely within the warehouse environment.
Procurement/Distribution Worker	Operated in the monitored warehouse area, responsible for moving goods and materials. The prototype tracked their activities to test object recognition, motion detection, and real-time logging.
Stakeholder	Represents management or clients who evaluate whether the prototype meets business needs, such as improving security, operational visibility, or process efficiency.
QC/Insurance worker	Validate whether the camera system accurately detects, records, and reports warehouse activities. They ensure the system meets quality and compliance standards during functional testing.

Table 2. Description of use cases

Use cases	Description
Login	Login allows all system users to access the warehouse monitoring platform securely. When launching the application, the system will prompt the user to enter a username and password.
Main Menu	The Main Menu serves as the central navigation interface after a successful login. All actors can utilize it to access the system's primary features, including product information, environmental monitoring, and camera surveillance.
Product List	The Product List enables administrators and procurement or distribution personnel to view detailed information about the inventory stored in the warehouse.
Temperature Monitoring	Temperature Monitoring allows administrators and quality control or assurance personnel to monitor warehouse temperature levels in real time.
Humidity Monitoring	Humidity Monitoring provides administrators and QC/Assurance personnel with real-time insight into the humidity conditions within the warehouse.
Physical Conditions	Physical Condition is designed to help administrators and quality assurance staff check the physical state of goods within the warehouse.
Camera Monitoring	Camera Monitoring empowers all actors, especially administrators and security guards, to visually oversee warehouse operations through the camera system.

To describe the relationship between the actors and each interface available in the system, a general use case diagram is used as a visual representation that provides a thorough understanding of how each actor will operate the system. (Sjödin et al., 2018). The general use case diagram is shown in Figure 2, illustrating the workflow of all system roles, including Administrators, Procurement/Distribution Workers, Stakeholders, and QC/Assurance Workers. Furthermore, to provide a more detailed description of each actor's workflow, separate use case diagrams were developed that specifically describe the interactions of each role in more depth. Examples of such diagrams, which contain workflows for Administrators, Procurement/Distribution Workers, Stakeholders, and QC/Assurance Workers, are presented in Figure 3 and Figure 4.

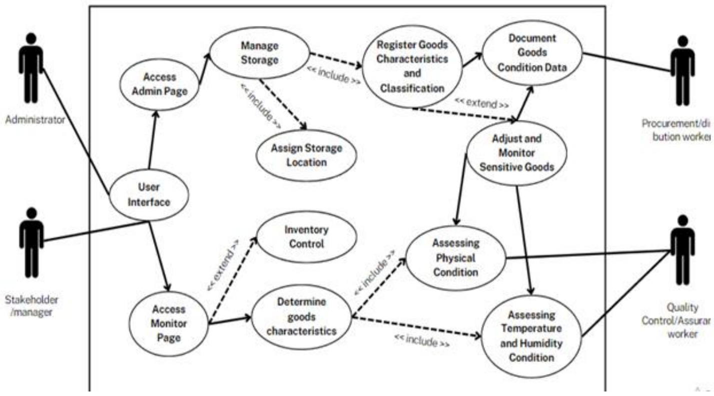

Figure 2. Inventory Control Use Case Diagram

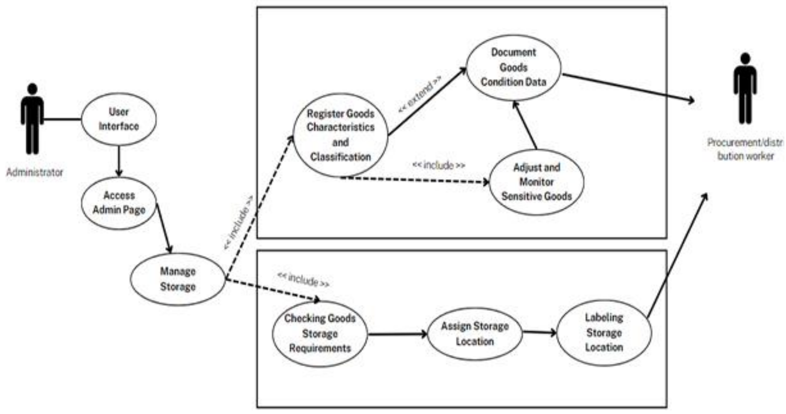

Figure 3. Goods Identification Use Case Diagram

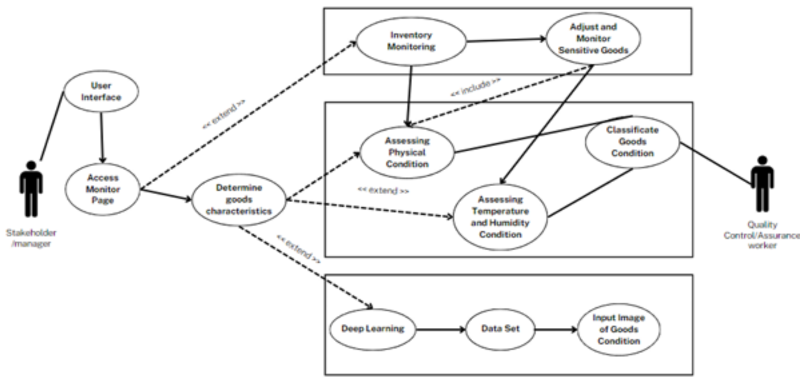

Figure 4. Goods Assessment Use Case Diagram

To ensure the robustness and functionality of RFID, we conducted black-box testing to evaluate its performance from an end-user perspective. (Verma et al., 2017)These tests involve user interaction as a parameter to identify unexpected behaviors, errors, or vulnerabilities that may arise during real-time use.

Table 3. Testing Spectrum

Type of Testing	Testing Type	Specifications	Who will test?	General Scope
Integration	White & Black Box Testing	Low and high-level Design	Programmers who write the code they test	Multiple classes
Functional	Black box testing	High-Level Design	Independent testers	Entire product
System	Black box testing	Requirements Analysis Stage	Independent testers	Whole product in a representative environment
Acceptance	Black box testing	Requirements Analysis Stage	Customer/User	The entire product in the customer environment
Regression	White & Black Box Testing	High-Level Design Modified Documentation	Programmer or Independent tester	Can be for any of the above

In functional testing, RFID is treated as a black box, and test cases are selected based on system design requirements or specifications. The expected results, referred to as test results, include specifications, hand-calculated values, and simulation results, with primary emphasis on evaluating the external behavior of software entities.

To ensure optimal system performance, the sustainability of this innovation must undergo a thorough testing phase. (Triki-Lahiani et al., 2018). Testing was conducted through two main approaches. First, functionality testing aims to ensure that the system operates appropriately based on three leading indicators: the completeness and reliability of functions on each interface, the level of system security, and the level of utility in supporting user activities. Second, usability testing was conducted by distributing surveys to various related parties to evaluate four main aspects, namely the accuracy of the system in delivering information, interface aesthetics, ease of use, and ease of access to information. The results of the system functionality testing are shown in Table 5, while the results of the system usability evaluation are presented in Table 6.

Table 4. Functional testing using test cases

Scenario	Data Value 1	Data Value 2	Expected result	Result
Real-time Monitoring	Open the RFID application. Navigate to "Camera Monitoring"	Select a camera for live monitoring. Observe the display for the selected camera feed.	The RFID app should display a live video feed from the selected camera. The feed should be clear, without significant lag, and accurately represent the real-time environment.	Pass
Activity Log Accuracy	Open the RFID app. Navigate to "Recent Products". Review "Product List"	Navigate to "Manage Products". Verify or set the product.	The activity log should accurately record all activities related to the inventory. Each log entry should include information on product specifications, quality metrics, production history, and other relevant details.	Pass
Sistem Pemberitahuan	Open the RFID application. Trigger a simulation of a critical inventory event (e.g., low stock).	Navigate to "Temperature Monitoring" or "Humidity Monitoring". Check the system-generated notification associated with the event.	The RFID application should immediately generate notifications for critical inventory events. The notification should include relevant details and give a clear indication of the issue.	Pass

Table 5. Functionality testing results.

Test Case Type	Description	Expected	Status
Functional	Main Menu Interface	The user can access the main menu	Pass
	Product List Interface	Users can access the Product List menu, Product Management, and return to the main menu.	Pass
	Temperature Monitoring Interface	Users can access the Temperature Monitoring menu and return to the main menu.	Pass
	Humidity Monitoring Interface	Users can access the Humidity Monitoring menu and return to the main menu	Pass
	Physical Condition Interface	Users can access the Physical Condition menu, check Item Condition, and return to the main menu.	Pass
	Camera Monitoring Interface	Users can access the Camera Monitoring menu, check Camera View by Aisle and Shelf, and return to the main menu.	Pass
	Exit	Users can access the Log out button after accessing any menu and log out	Pass
Security	Login Session/ Login Interface	Users can log in or register smoothly	Pass
Utility	Overall Prototype Function	Users can log in, access menus, and log out smoothly	Pass

Table 6. Usability testing results

Usability Testing Aspect	Result
Suitability	Pass
Aesthetics	Pass
Usability	Pass
Convenience of getting information	Pass
The convenience of using the prototype	Pass

Conclusion

Using the RFID system is straightforward, although it can be challenging for users unfamiliar with it. After successfully logging into the system, users can begin accessing the various monitoring features. However, it takes a certain amount of time to adapt to the interface, which tends to be rigid. Some features, such as the main page filled with buttons and statistical data, as well as temperature and humidity monitoring, are considered quite complex. As a result of this preliminary study, the potential application of CVT in IMS proved to be very promising. Supported by advances in artificial intelligence, machine learning, and sensor technology, CVT applications are projected to expand further in supporting inventory management. Considering the direction of development, it is evident that CVT will continue to be a crucial component in shaping the future of inventory management systems, presenting new opportunities in terms of automation, optimization, and innovation.

Through analysis, it has been determined that current technologies can significantly support the advancement of agricultural automation in small-scale farming by offering benefits such as low cost, high efficiency, and high precision. Nonetheless, considerable challenges remain. As technology continues to expand into new areas of application, additional technical obstacles are expected to emerge, necessitating further research and innovation to address them. Moreover, RFID systems generate large volumes of real-time data, which, without proper filtering and processing, may overwhelm storage and decision-making processes. While CVT effectively supports RFID by covering its weaknesses, the combined implementation introduces new layers of technical and operational complexity that must be addressed for successful deployment in warehouse environments. It is anticipated that, in the future, computer vision technology will be increasingly integrated with intelligent systems such as deep learning, enabling its application across all aspects of agricultural production management through the utilization of large-scale datasets. This integration is expected to enhance the ability to address current agricultural challenges more effectively, improving the economic viability, overall performance, and robustness of agricultural automation systems. As a result, it will accelerate the advancement of agricultural equipment and systems toward greater intelligence and efficiency.

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