ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 7 (July 2026)

Intelligent Laboratory Asset Monitoring Using OCR-Integrated Borrowing Logging and Predictive Equipment Maintenance

Mike Louie C. Enriquez, Meizl Ann F. Manlupig, Jose G. Moral Jr. and Loretta O. Cruz
National University Baliwag
locruz@nu-baliwag.edu.ph

Date Submitted:
March 26, 2026

Date Accepted:
May 17, 2026

Date Published:
July 28, 2026

DOI:
10.5281/zenodo.21637523

ABSTRACT

Effective laboratory management demands accurate asset tracking, reduced transaction latency, and reliable record integrity to support operational efficiency and research continuity. This study proposes and evaluates an OCR-driven intelligent laboratory asset monitoring system designed to automate equipment logging without requiring additional tagging infrastructure. Comparative analysis against Manual & Excel, QR Code, and RFID-based systems demonstrates that the proposed framework significantly improves operational performance, reducing average logging time from 80 seconds to 37 seconds while increasing inventory record accuracy from 70% to 96.5%. By leveraging optical character recognition to capture existing printed or engraved equipment identifiers, the system minimizes deployment complexity and integrates seamlessly within legacy laboratory environments. The centralized database architecture enables real-time validation, structured identification enforcement, and transparent status transitions, enhancing data consistency and user confidence. Despite RFID achieving marginally higher peak accuracy, the OCR-driven approach attained the highest usability rating, reflecting strong user acceptance and workflow efficiency. Overall, the findings position the proposed system as a scalable, cost-effective, and infrastructure-independent solution that balances efficiency, accuracy, and usability, providing a practical model for the digital transformation of laboratory asset management.

Keywords: *asset tracking, equipment optimization, lab management, optical character recognition, predictive maintenance*

INTRODUCTION

Laboratories play a pivotal role in advancing scientific research, education, and technological innovation (Nursuwars et al., 2023). The efficiency and reliability of laboratory operations, however, heavily depend on the proper management of equipment and resources. Misplaced or improperly maintained assets, unauthorized usage, and delayed maintenance schedules can compromise research outcomes, reduce productivity, and increase operational costs (Al-Zoubi et al., 2022). Traditional methods of asset management, which often rely on manual logging and periodic maintenance checks, are prone to human error, inconsistencies, and reactive interventions that fail to prevent unexpected equipment failures (Kusumojati & Mediawati, 2024).

Recent advancements in automation and machine learning have paved the way for intelligent asset management systems capable of real-time tracking and predictive maintenance (Mohan, 2025). Optical Character Recognition (OCR) enables automated identification (Kushavaha, 2024) and logging of equipment by reading labels, codes, or tags, minimizing errors associated with manual entry and ensuring accurate usage records (Nanna et al., 2023). Predictive maintenance algorithms, driven by historical usage patterns and operational data, can forecast equipment degradation and required interventions, reducing downtime and extending the operational lifespan of laboratory assets (Rahman et al., 2025). Few laboratory systems combine automated borrowing logs with predictive maintenance. This study proposes an OCR-based asset monitoring system that improves resource management, accountability, and equipment use (Abd Wahab et al., 2024). The research demonstrates the feasibility, efficiency, and scalability of such an integrated approach, providing a foundation for smarter laboratory management.

Laboratory environments face persistent challenges in managing equipment efficiently, including misplaced or untracked assets, unauthorized usage, and inconsistent maintenance schedules (Achouch et al., 2022). These issues reduce productivity and increase downtime, while manual logging and reactive maintenance are often unreliable and unable to prevent failures (Shen Chua et al., 2025). A real-time asset monitoring system is needed to improve maintenance and equipment use. This study aims to develop an intelligent laboratory asset monitoring system that integrates Optical Character Recognition (OCR) for automated borrowing logging with predictive maintenance analytics. Specifically, the research seeks to (1) design and implement an OCR-based module to accurately identify and log equipment usage, (2) apply machine learning algorithms to predict maintenance requirements based on historical usage data, and (3) evaluate the system's effectiveness in improving asset accountability, reducing unauthorized usage, and minimizing unplanned downtime. The overarching objective is to provide a scalable and efficient framework that enhances laboratory management, promotes proactive maintenance, and supports data-driven decision-making in research environments.

METHODS

This study used a developmental-evaluative design to develop and assess an OCR-based laboratory asset monitoring system with predictive maintenance at National University Baliwag. It measured recognition accuracy, logging speed, utilization, and maintenance lead time, while usability was evaluated through surveys and interviews.

Research Design

The OCR system uses a multi-stage pipeline with image preprocessing, segmentation, and semantic validation, enhanced by a Recognition Validity Feedback Loop for database cross-checking and error reduction. A confidence-based mechanism triggers recapture when accuracy is low, improving reliability under real-world conditions.

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 7 (July 2026)

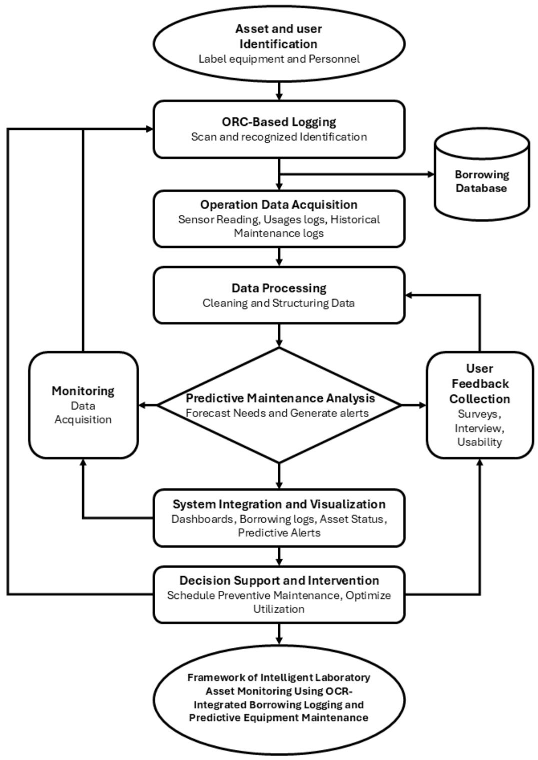

Figure 1. *Framework of the OCR-Integrated Intelligent Laboratory Asset Monitoring System with Predictive Maintenance and Feedback Mechanism.*

Figure 1 illustrates the system workflow from OCR-based asset logging to predictive maintenance and dashboard monitoring, with continuous feedback improving system components for adaptive asset management. System performance depends on image quality, lighting, and label clarity, while predictive accuracy relies on sufficient historical data. The pilot was limited to one laboratory, which may affect generalization, and maintenance predictions are based on usage patterns rather than direct mechanical condition.

Materials and Tools

The system was developed as an integrated hardware–software solution for camera-based Optical Character Recognition (OCR) and vision-assisted utility and tool detection, enabling automatic logging of equipment usage into a centralized dashboard. A server workstation equipped with an Intel® Core™ i5 processor, 8 GB RAM, and a 256 GB SSD running Windows 11 hosted the Flask-based web application, database, and computer vision modules. Client devices included Android smartphones (Android 10 or higher, ≥4 GB RAM) for image capture and laboratory desktop computers (Intel® Core™ i5, 4 GB RAM) for dashboard access. A dedicated local Wi-Fi router supported real-time data transmission between clients and the server.

High-resolution cameras integrated into client devices were used to capture equipment labels and visual features. Image data were processed using OpenCV for image preprocessing and camera vision tasks, and Tesseract OCR via pytesseract for extracting alphanumeric equipment identifiers. Recognized data were automatically matched with database records, triggering real-time status updates and usage logs on the monitoring dashboard. The software stack utilized Flask 3.0.2 as the back-end framework, Python 3.11 for application logic and image processing, SQLite3 for structured data storage, and Jinja2 for dynamic content rendering. The front-end interface was developed using HTML5, CSS3, and JavaScript to ensure responsive dashboard visualization.

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 7 (July 2026)

System Design

The proposed system uses a multi-layer intelligent architecture that integrates OCR-based asset identification, automated transaction logging, predictive maintenance, and decision support within a unified asset management framework. It is designed for efficiency, scalability, data integrity, and real-time operation.

The architecture has four layers: acquisition, processing, analytics, and decision support. The acquisition layer captures equipment labels via OCR and validates them against a centralized registry to ensure accurate identification and avoid duplicates. The processing layer manages transactions, updates equipment status and timestamps, and records user interactions. It also consolidates operational data such as usage frequency, duration, idle time, and maintenance history, which are cleaned, normalized, and structured for analysis (Nitayavardhana et al., 2025).

The equipment database stored key attributes including equipment ID, name, category, laboratory location, operational status (available, borrowed, or under maintenance), usage frequency, maintenance history, and predicted maintenance schedules. These data enabled automated borrowing logs, real-time equipment monitoring, and predictive maintenance analytics within the intelligent laboratory management system.

Figure 2. User Login Interface of the OCR-Integrated Borrowing Logging and Predictive Equipment Maintenance.

The user login interface shown in Fig. 2 serves as the secured gateway to the system. It implements credential verification and role classification before granting dashboard access. The interface contains structured input fields for user identification and password authentication, ensuring controlled entry into the system environment. Access privileges are dynamically assigned upon verification, restricting unauthorized interaction with administrative modules and sensitive data. This authentication mechanism reinforces data security, accountability, and system reliability.

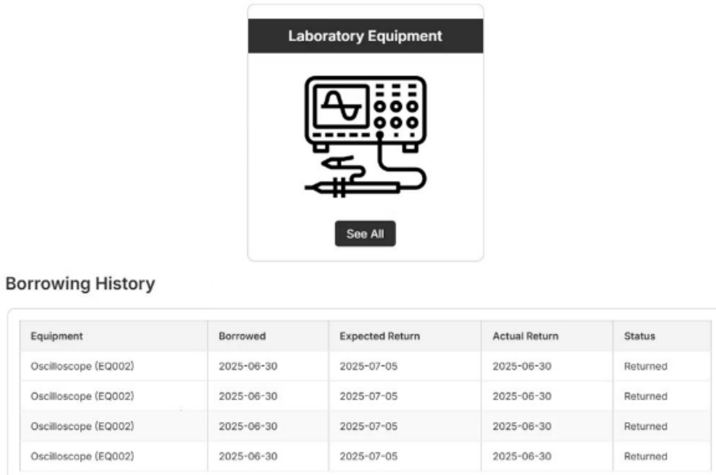

Figure 3. Borrowing History and Equipment Overview Interface of the Laboratory Equipment Tracking and Inventory System.

The borrowing history and equipment analytics interface illustrated in Fig. 3 provides detailed transaction traceability. It presents structured records including equipment identification, borrower information, borrowing timestamp, expected return schedule, actual return time, and current operational status. This interface supports transparency and accountability by enabling both users and administrators to review borrowing patterns and compliance metrics. Integrated analytics further assist in identifying high-utilization assets and recurrent maintenance requirements.

Data Gathering Procedure

Data collection was carried out through a four-week pilot deployment of the OCR-based asset monitoring system at the National University Baliwag engineering laboratory. Forty-two participants were trained on standardized borrowing and return procedures, and all equipment was pre-registered in a centralized database. During the pilot, all transactions were automatically logged to measure processing time and efficiency. System outputs were compared with reference records to assess recognition accuracy, and weekly audits were conducted to check data consistency. Usage patterns and maintenance predictions were analyzed from system logs and validated against actual records, while a post-implementation survey was used only for usability evaluation.

RESULTS AND DISCUSSION

The OCR-based laboratory asset monitoring system showed significant improvements in efficiency, accuracy, and usability compared to manual and Excel-based methods. It also performed competitively against QR and RFID systems. Unlike QR and RFID, it does not require additional tags, using existing equipment labels instead. This reduces setup cost and complexity while enabling easy integration into existing laboratory systems with high accuracy and user acceptance.

Table 1: Comparison of Manual System and OCR Code–Driven System Performance

Metric	Manual & Excel	QR Code System	RFID System	OCR-Driven System
Preparation time per item (sec)	0	25	40	20
Average logging time (sec)	80	6	1.3	37
Inventory record accuracy (%)	70	93	98	96.5
Borrow transaction time (sec)	58	15	4.5	30
Preparation Time per Item (sec)	0	25–40	60–120	10–20
System Usability Score (0–100)	70 (Moderate)	88 (High)	90 (High)	92 (Excellent)

The comparative analysis of Manual & Excel, QR Code, RFID, and OCR systems shows clear differences in performance (Table 1). RFID had the highest setup time (40 s) due to tagging, followed by QR (25 s) and OCR (20 s), while Manual required none. For logging speed, Manual was slowest (80 s), while RFID (1.3 s) was fastest, followed by QR (6 s) and OCR (37 s). Accuracy improved with automation: Manual (70%), QR (93%), RFID (98%), and OCR (96.5%), with RFID performing best due to minimal human intervention. Borrowing times followed the same trend, with RFID fastest (4.5 s) and Manual slowest (58 s). Usability scores showed OCR highest (92), followed by RFID (90), QR (88), and Manual (70).

Overall, RFID offers best speed and accuracy, OCR provides highest usability, and QR Code balances cost and performance. These findings are aligned with (Wang et al., 2024), who highlighted that digitized systems that integrate transaction history significantly improve asset management practices.

User Experience

The OCR system improved user experience over manual and Excel methods and was comparable to QR and RFID systems. Unlike QR/RFID, it requires no tagging or relabeling, reducing setup time and operational effort. Its use of existing labels improves convenience, practicality, and scalability in laboratory environments. These findings align with previous studies such as (Fajar et al., 2025; Bandara et al., 2024; Sukron et al., 2024), which documented similar gains in user satisfaction following the adoption of equipment management systems. The OCR system integrates borrowing logs with predictive maintenance, enabling proactive asset management and lifecycle optimization. It streamlines transactions through automation, improving speed and reducing delays, while real-time updates enhance transparency and accuracy. The combination of automated recognition, simplified interface design, and transparent transaction tracking supports both operational efficiency and user satisfaction.

CONCLUSION

This study developed and evaluated an OCR-driven intelligent laboratory asset monitoring system and compared its performance with Manual and Excel-based, QR code, and RFID systems. Findings show that while RFID achieved the fastest logging time at 1.3 seconds and the highest inventory accuracy at 98 percent, the proposed OCR-driven system demonstrated the best overall balance of efficiency, accuracy, and usability without requiring additional tagging infrastructure. The OCR system reduced average logging time from 80 seconds in the manual method to 37 seconds and decreased borrowing transaction time from 58 seconds to 30 seconds, while improving inventory record accuracy from 70 percent to 96.5 percent and achieving the highest System Usability Score of 92, rated excellent. Although QR and RFID systems offer faster transaction speeds, they require preparation time per item of 25 and 40 seconds, respectively, increasing implementation effort and cost. Therefore, the OCR-driven system is recommended as a scalable and cost-effective solution for laboratory asset management, particularly for institutions with existing labeled equipment, and future improvements should focus on optimizing processing speed, enhancing OCR robustness under varying environmental conditions, and integrating cloud-based synchronization and predictive maintenance analytics to further improve long-term efficiency and sustainability.

Acknowledgements

The authors extend their sincere gratitude to the Department of Computer Engineering at National University–Baliwag for their invaluable support and guidance throughout the completion of this research. Appreciation is also expressed to all individuals who contributed to the development, implementation, and refinement of the system, as well as to those who provided technical assistance and constructive feedback that strengthened the overall quality of the study.

References

Abd Wahab, N. H., Hasikin, K., Wee Lai, K., Xia, K., Bei, L., Huang, K., & Wu, X. (2024a). Systematic review of predictive maintenance and digital twin technologies challenges, opportunities, and best practices. *PeerJ Computer Science*, *10*, e1943. https://doi.org/10.7717/peerj-cs.1943

Abd Wahab, N. H., Hasikin, K., Wee Lai, K., Xia, K., Bei, L., Huang, K., & Wu, X. (2024b). Systematic review of predictive maintenance and digital twin technologies challenges, opportunities, and best practices. *PeerJ Computer Science*, *10*, e1943. https://doi.org/10.7717/peerj-cs.1943

Achouch, M., Dimitrova, M., Ziane, K., Sattarpanah Karganroudi, S., Dhouib, R., Ibrahim, H., & Adda, M. (2022). On Predictive Maintenance in Industry 4.0: Overview, Models, and Challenges. *Applied Sciences*, *12*(16), 8081. https://doi.org/10.3390/app12168081

Al-Zoubi, A. Y., Dmour, M., & Aldmour, R. (2022). Blockchain as a Learning Management System for Laboratories 4.0. *International Journal of Online and Biomedical Engineering (iJOE)*, *18*(12), 16–34. https://doi.org/10.3991/ijoe.v18i12.33515

Bandara, I., Simpson, O., & Sun, Y. (2024). Optimizing Efficiency Using a Low-Cost RFID-Based Inventory Management System. *2024 International Wireless Communications and Mobile Computing (IWCMC)*, 1729–1733. https://doi.org/10.1109/IWCMC61514.2024.10592581

Fajar, M., Azhar, R., Anshori, Y., & Laila, R. (2025). *Optimization of Inventory Management with QR Code Integration and Sequential Search Algorithm: A Case Study in a Regional Revenue Office*. *9*(2).

Kushavaha, K. (2024). OCR: Optical Character Recognition. *International Journal for Research in Applied Science and Engineering Technology*, *12*(4), 3854–3856. https://doi.org/10.22214/ijraset.2024.60794

Kusumojati, P. P., & Mediawati, E. (2024). Web-Based Asset Management Information Systems in Higher Education. *International Journal of Business, Law, and Education*, *5*(1), 398–411. https://doi.org/10.56442/ijble.v5i1.382

Mohan, V. N. (2025). Intelligent Preventive Maintenance: The Rise of Usage-Based Scheduling. *Journal of Computer Science and Technology Studies*. https://doi.org/10.32996/jcsts.2025.7.129

Nanna, N., Chanthawong, N., & Buajarern, J. (2023). Design and development of OCR software for remote measurement and calibration. *Journal of Physics: Conference Series*, *2653*(1), 012012. https://doi.org/10.1088/1742-6596/2653/1/012012

Nitayavardhana, P., Liu, K., Fukaguchi, K., Fujisawa, M., Koike, I., Tominaga, A., Iwamoto, Y., Goto, T., Suen, J. Y., Fraser, J. F., & Ng, P. Y. (2025). Streamlining data recording through optical character recognition: A prospective multi-center study in intensive care units. *Critical Care*, *29*(1), 117. https://doi.org/10.1186/s13054-025-05347-1

Nursuwars, F. M. S., Audika, R. F., Sutisna, S., & Taufiqurrahman, I. (2023). Smart Laboratory Using Radio Frequency Identification (RFID) Based on The Internet of Things. *Journal of Computer Engineering, Electronics and Information Technology*, *1*(2), 75–90. https://doi.org/10.17509/coelite.v1i2.51618

Rahman, M. A., Shahrior, M. F., Iqbal, K., & Abushaiba, A. A. (2025). Enabling Intelligent Industrial Automation: A Review of Machine Learning Applications with Digital Twin and Edge AI Integration. *Automation*, *6*(3), 37. https://doi.org/10.3390/automation6030037

Shen Chua, H., A/L Betharajoo, S. K., A/L Paramasivam, S., Anandaraj Doss, S., Thing Goh, T., & Chen Gee, C. (2025). Enhancing Compliance and Process Monitoring in Engineering Labs with IoT-Driven RFID Solutions. *Jurnal Kejuruteraan*, *37*(6), 3045–3054. https://doi.org/10.17576/jkukm-2025-37(6)-38

Sukron, Moh., Ramadhan, M. R., & Sihabillah, A. (2024). Design of a Quick Response Code-Based Infrastructure Management Information System. *International Journal of Engineering and Computer Science Applications (IJECSA)*, *3*(2), 89–96. https://doi.org/10.30812/ijecsa.v3i2.4653

Wang, R., Chen, L., Liu, J., & Tian, L. (2024). Design and Development of an Intelligent Laboratory Management System Based on STM Processors. *International Journal of Advanced Network, Monitoring and Controls*, *9*(3), 40–46. https://doi.org/10.2478/ijanmc-2024-0025