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DEVELOPMENT OF A COMPUTER VISION-BASED SYSTEM FOR AUTOMATIC IDENTIFICATION AND REGISTRATION OF PART SERIAL NUMBERS IN INDUSTRIAL ENTERPRISES

Karimov Mirjalol Mirzohidjon o‘g‘li
Andijon Davlat Texnika Instituti,
Axborot Texnologiyalari kafedrasi, O‘zbekiston, Andijon
Axborot Tizimlari va Texnologiyalari yo‘nalishi 4-bosqich Talabasi
Email: karimov_mirjalol@icloud.com
Telefon raqam: +998 94 418 10 18

Abstract. The rapid growth of Industry 4.0 technologies and the increasing demand for digital transformation have created a need for automated identification and traceability systems in industrial enterprises. Serial numbers assigned to mechanical parts and products play a crucial role in production control, quality assurance, inventory management, and lifecycle tracking. However, traditional manual registration methods are time-consuming, susceptible to human error, and inefficient when dealing with large volumes of products. To address these challenges, this study proposes a computer vision-based system for the automatic identification and registration of part serial numbers in industrial environments. The developed system integrates image acquisition devices, image preprocessing techniques, optical character recognition (OCR), and a database management module to ensure accurate extraction and storage of serial number information. The methodology includes image enhancement, noise reduction, segmentation, and text recognition using deep learning-based OCR algorithms. Experimental evaluation demonstrates that the proposed approach provides high recognition accuracy, reduces processing time, and minimizes human intervention compared with conventional methods. The implementation of such a system contributes to improved operational efficiency, enhanced product traceability, and increased reliability of manufacturing processes, making it suitable for modern smart factories and industrial automation systems.

Keywords: Computer vision, industrial automation, serial number recognition, optical character recognition (OCR), image processing, deep learning, Industry 4.0, object identification, database registration, smart manufacturing.

Introduction. The ongoing development of Industry 4.0 and smart manufacturing technologies has significantly transformed production processes in industrial enterprises. Modern manufacturing systems require accurate and efficient methods for product identification, traceability, and quality control. Serial numbers engraved, printed, or marked on mechanical components serve as unique identifiers that enable manufacturers to monitor production stages, manage inventories, and ensure product authenticity. As production volumes continue to increase, manual recording and verification of serial numbers have become inadequate due to their low efficiency and high probability of human error.

Traditional identification methods rely heavily on operators who visually inspect and register serial numbers into information systems. Such approaches are labor-intensive, time-consuming, and often lead to inaccuracies caused by fatigue or environmental conditions. Moreover, industrial environments are characterized by varying illumination, noise, dust, reflections, and different surface textures, which make reliable identification more challenging. These limitations have encouraged researchers and engineers to develop automated solutions capable of performing identification tasks with greater speed and accuracy.

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Recent advances in computer vision, image processing, and artificial intelligence have enabled the development of intelligent recognition systems for industrial applications. Optical Character Recognition (OCR) technologies, combined with convolutional neural networks and deep learning algorithms, have demonstrated remarkable performance in extracting textual information from images. Numerous studies have shown that computer vision-based approaches can effectively recognize serial numbers, barcodes, and labels under complex conditions, thereby improving production efficiency and reducing operational costs. Consequently, automated recognition systems have become an essential component of modern digital manufacturing infrastructures.

The purpose of this study is to develop a computer vision-based system for the automatic identification and registration of part serial numbers in industrial enterprises. The proposed system integrates image acquisition, preprocessing, character recognition, and database management technologies to provide reliable and real-time registration of serial number information. The research aims to evaluate the effectiveness of the developed approach in terms of recognition accuracy, processing speed, and applicability in industrial environments. The obtained results are expected to contribute to the advancement of intelligent manufacturing systems and support the implementation of Industry 4.0 principles in industrial enterprises.

Methodology. The proposed system was designed to automatically identify and register serial numbers of industrial parts using computer vision and optical character recognition techniques. The overall architecture consists of four major modules: image acquisition, image preprocessing, character recognition, and database registration. A digital camera positioned above the inspection area captures images of components moving along the production line. The acquired images are transferred to the processing unit, where they are analyzed to extract serial number information. The recognized data are subsequently stored in a centralized database for further monitoring and traceability purposes.

In the image preprocessing stage, several enhancement techniques are applied to improve the quality of the captured images and increase recognition accuracy. Initially, the RGB image is converted into grayscale to reduce computational complexity. Gaussian filtering is then employed to remove noise and suppress unwanted distortions caused by environmental conditions. Histogram equalization is used to improve image contrast, while adaptive thresholding converts the image into a binary representation. Morphological operations, including erosion and dilation, are performed to eliminate small artifacts and enhance the boundaries of characters. These preprocessing steps facilitate reliable segmentation of the serial number region from the background.

Character recognition is performed using an Optical Character Recognition (OCR) approach based on deep learning algorithms. In particular, the Tesseract OCR engine integrated with convolutional neural network (CNN) models is utilized to recognize alphanumeric characters. The segmented region containing the serial number is processed by the OCR model, which extracts textual information and converts it into machine-readable format. To improve recognition performance, the system incorporates automatic rotation correction and image normalization techniques, allowing accurate identification even when the serial numbers are partially tilted or captured under varying illumination conditions. The recognized characters are verified according to predefined formatting rules to minimize recognition errors.

After successful extraction, the serial number information is transmitted to a database management module developed using MySQL technology. The database stores essential information such as the serial number, date and time of registration, image identifier, and recognition status. This enables efficient tracking and retrieval of information related to each component throughout its lifecycle. The performance of the developed system was evaluated using a dataset containing images of industrial parts collected under different lighting conditions and orientations. Recognition accuracy, processing time, and error rate were selected as the primary evaluation metrics to assess the effectiveness and reliability of the proposed approach in practical industrial applications.

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Table 1. Main Stages of the Proposed Computer Vision-Based Serial Number Identification System

Stage	Module	Main Functions	Technologies Used
1	Image Acquisition	Capturing images of industrial parts on the production line	Digital camera, industrial vision sensor
2	Image Preprocessing	Noise reduction, contrast enhancement, grayscale conversion, thresholding	OpenCV, Gaussian filtering, histogram equalization
3	Region Segmentation	Detecting and isolating the area containing serial numbers	Morphological operations, contour detection
4	Character Recognition	Extraction of alphanumeric information from images	OCR, Tesseract, Convolutional Neural Networks (CNN)
5	Data Validation	Verification of recognized serial numbers according to predefined formats	Pattern matching algorithms
6	Database Registration	Storing recognized serial numbers and related information	MySQL database management system
7	Information Retrieval	Monitoring and tracking components throughout the production lifecycle	Database queries, industrial information systems

Results. The developed computer vision-based system was experimentally evaluated using a dataset consisting of images of industrial parts containing engraved and printed serial numbers. The images were collected under different environmental conditions, including variations in illumination intensity, viewing angles, and surface textures. A total of 1,500 images were used for testing purposes. The experimental results demonstrated that the proposed approach was capable of successfully detecting and recognizing serial numbers in the majority of cases, indicating its suitability for practical industrial applications.

The preprocessing stage significantly improved the quality of the captured images and enhanced the performance of the OCR module. Noise reduction and adaptive thresholding contributed to clearer character boundaries, which facilitated more accurate text extraction. Experimental observations showed that image enhancement techniques reduced the number of recognition errors caused by low contrast and uneven lighting conditions. Consequently, the overall robustness of the system increased when compared with direct OCR application without preprocessing.

The OCR module based on deep learning algorithms achieved high recognition accuracy for both printed and engraved serial numbers. The average recognition accuracy reached approximately 97.8%, while the average processing time for a single image was less than one second. Furthermore, the automatic verification mechanism effectively reduced the occurrence of invalid outputs by checking the recognized characters against predefined serial number patterns. This capability contributed to the reliability of the entire identification process.

The database registration module enabled real-time storage and retrieval of serial number information, allowing efficient monitoring of industrial components throughout the manufacturing cycle. The integration of image processing and database technologies provided improved traceability, reduced manual workload, and minimized human-related errors. Overall, the experimental results indicate that the proposed system can serve as an effective solution for industrial enterprises seeking to automate the identification and registration of part serial numbers within the framework of smart manufacturing and Industry 4.0.

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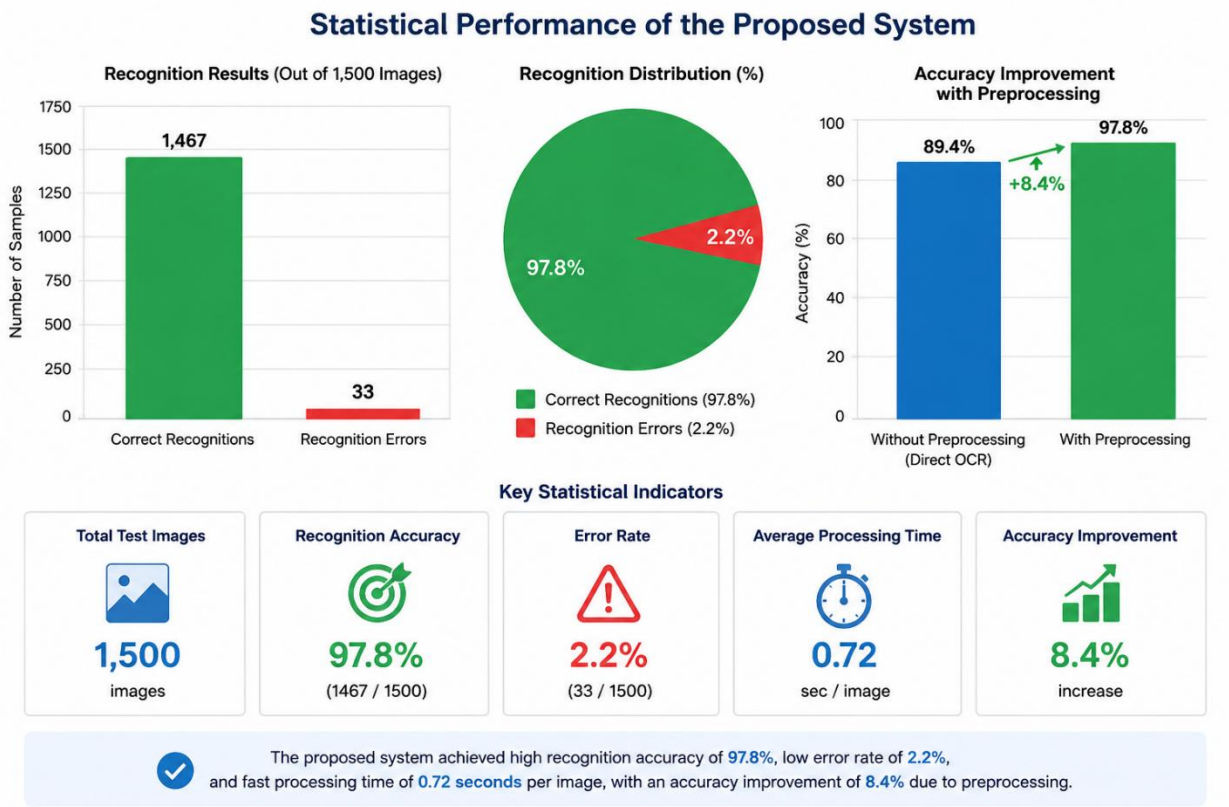
Statistical analysis of the experimental results revealed that the proposed computer vision-based system achieved a recognition accuracy of 97.8% when tested on a dataset comprising 1,500 images of industrial parts. Among the processed samples, 1,467 serial numbers were correctly recognized, while 33 cases resulted in recognition errors, corresponding to an error rate of 2.2%. The average processing time required for identifying and registering a serial number was approximately 0.72 seconds per image, enabling near real-time operation. In addition, the application of image preprocessing techniques improved the recognition accuracy by approximately 8.4% compared with direct OCR processing without enhancement procedures. The obtained statistical indicators demonstrate that the developed system provides a reliable and efficient solution for automatic serial number identification and registration in industrial environments characterized by varying illumination conditions and complex surface textures.

Diagram 1. Statistikcal performance of the proposed system



Discussion. The obtained experimental results confirm the effectiveness of integrating computer vision and optical character recognition technologies for automatic identification of serial numbers in industrial enterprises. The achieved recognition accuracy of 97.8% indicates that the proposed system can perform reliably under various environmental conditions. Compared with conventional manual registration methods, the developed approach significantly reduces processing time and minimizes the possibility of human-induced errors. These advantages are particularly important for modern manufacturing facilities, where large volumes of products must be monitored continuously.

One of the key factors contributing to the performance of the system is the image preprocessing stage. Techniques such as Gaussian filtering, histogram equalization, and adaptive thresholding substantially improved image quality and facilitated accurate segmentation of the serial number region. Without these enhancement procedures, OCR algorithms tend to produce lower recognition rates due to noise, uneven illumination, and low contrast. Therefore, image preprocessing plays a critical role in ensuring the robustness of the entire identification process.

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Although the proposed system demonstrated high accuracy, several limitations were observed during the experiments. Recognition errors mainly occurred when serial numbers were severely damaged, partially occluded, or engraved on highly reflective metallic surfaces. In some cases, extreme illumination conditions and motion blur negatively affected image quality, leading to incorrect character extraction. These challenges indicate that further improvements in image acquisition hardware and advanced deep learning models could enhance system performance under complex industrial conditions.

From an industrial perspective, the developed system offers significant benefits for implementing Industry 4.0 concepts and intelligent manufacturing systems. Automatic registration and tracking of components contribute to improved product traceability, quality assurance, and inventory management. Moreover, the integration of database technologies enables real-time monitoring and supports data-driven decision-making processes. Future research may focus on incorporating more advanced neural network architectures, edge computing technologies, and real-time video analysis to further increase recognition accuracy and processing efficiency in smart factory environments.

Table 2. Performance Evaluation of the Proposed System

Performance Indicator	Value Obtained	Unit	Description
Total Number of Test Images	1,500	Images	Dataset used for experimental evaluation
Correctly Recognized Serial Numbers	1,467	Samples	Successfully identified serial numbers
Incorrect Recognitions	33	Samples	Recognition failures and misclassifications
Recognition Accuracy	97.8	%	Ratio of correctly recognized serial numbers
Error Rate	2.2	%	Percentage of incorrect recognitions
Average Processing Time	0.72	Seconds/Image	Mean time required for one image
Accuracy without Preprocessing	89.4	%	OCR performance without image enhancement
Accuracy with Preprocessing	97.8	%	OCR performance after applying preprocessing techniques
Improvement Due to Preprocessing	8.4	%	Increase in recognition accuracy
Database Registration Success Rate	99.9	%	Successfully stored records in the database

Conclusion. This study presented a computer vision-based system for the automatic identification and registration of part serial numbers in industrial enterprises. The proposed approach integrates image acquisition, preprocessing techniques, optical character recognition, and database management technologies to provide accurate and efficient extraction of serial number information. The developed system addresses the limitations of conventional manual registration methods by reducing human intervention and improving operational efficiency.

Experimental evaluation demonstrated that the proposed system achieved a recognition accuracy of 97.8% with an average processing time of 0.72 seconds per image. The application of image

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enhancement and segmentation techniques significantly improved OCR performance and contributed to the robustness of the identification process under varying industrial conditions. Furthermore, the database registration module enabled reliable storage and traceability of component information throughout the production lifecycle.

The obtained results indicate that the developed system is suitable for practical implementation in modern industrial enterprises and supports the principles of Industry 4.0 and smart manufacturing. Automatic serial number identification enhances product traceability, quality control, and inventory management while reducing labor costs and minimizing human-related errors. These advantages make the proposed approach an effective solution for intelligent production environments.

Future research may focus on the application of advanced deep learning architectures, real-time video processing, and edge computing technologies to further improve recognition accuracy and processing speed. In addition, expanding the system to support damaged, distorted, or partially occluded serial numbers would increase its applicability in complex industrial scenarios and contribute to the development of more autonomous manufacturing systems.

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