Chalk Capture: An OpenCV based solution for accessible classroom notes

Ch. Ramesh[1], A. Chethan[2], Dwijesh Awasthi[3], M. Akhil[4], Md. Abuzar[5]
[1,2,3,4,5] *Vidya Jyothi Institute of Technology*

***Abstract*—This project proposes an automated classroom lecture note digitization system based on computer vision and document processing techniques. The system captures blackboard images using a camera-based acquisition module and performs image preprocessing operations such as grayscale conversion, noise filtering, thresholding, and perspective correction using OpenCV to enhance text visibility. Optical character recognition is applied to the processed images to extract textual content from chalk-written lecture notes. The recognized text is post-processed and formatted to generate structured PDF documents. These documents are stored on a centralized server and made accessible through a web-based interface, enabling efficient retrieval and remote access. The proposed system aims to improve text recognition accuracy under varying classroom conditions, reduce manual documentation effort, and provide a scalable framework for digital lecture content management.**

***Index Terms*—Computer Vision, Optical Character Recognition, Blackboard Content Digitization, Image Preprocessing, Lecture Note Capture, PDF Generation, Web-Based Learning System, Digital Education**

I. INTRODUCTION

The integration of digital technologies into the education sector has transformed the way teaching and learning processes are conducted. With the increasing emphasis on smart classrooms and e-learning platforms, there is a growing demand for automated systems that can efficiently capture, store, and distribute academic content. Despite these advancements, traditional blackboard-based teaching remains widely used in educational institutions due to its simplicity and effectiveness in concept explanation. However, this method heavily depends on students' ability to manually record lecture notes, which is often inefficient and unreliable.

Manual note-taking presents several challenges. Students may miss important information due to fast-paced lectures, unclear handwriting, limited visibility from seating positions, or temporary absence from class. Additionally, copying complex diagrams, equations, and structured explanations from the blackboard is time-consuming and prone to errors. These issues can negatively impact learning outcomes, especially during exam preparation, where complete and accurate notes are essential.

To address these limitations, automated lecture capture and digitization systems have emerged as a promising solution. Advances in computer vision and image processing enable the extraction of meaningful information from visual data captured in real-world environments [1], [7]. By using camera-based systems to periodically capture images of blackboards, lecture content can be preserved digitally without interrupting the teaching process. However, raw images captured in classrooms often suffer from challenges such as uneven lighting, shadows, glare, perspective distortion, and background noise, which reduce readability and affect text recognition accuracy.

Image preprocessing plays a crucial role in overcoming these challenges [1], [4]. Techniques such as grayscale conversion, noise filtering, adaptive thresholding, edge detection, and perspective correction help enhance image quality and isolate textual content from the background. Open-source computer vision libraries like OpenCV provide efficient and optimized implementations of these techniques [1], making them suitable for real-time or near-real-time classroom applications.

Following image enhancement, Optical Character Recognition (OCR) techniques are employed to convert visual text into machine-readable form [2], [3]. OCR enables automated extraction of chalk-

written or marker-written content from blackboard images. Although OCR accuracy can be affected by handwriting variations and image quality, the combination of robust preprocessing and post-processing significantly improves recognition performance [2], [4]. Extracted text can then be structured, formatted, and stored as digital documents.
Another important aspect of modern educational systems is accessibility. Digitized lecture notes are most effective when they are organized and made available through a centralized platform. Converting extracted content into Portable Document Format (PDF) ensures consistency, portability, and compatibility across devices. Hosting these PDFs on a web-based platform allows students to access lecture notes anytime and from anywhere, supporting self-paced learning and revision. This approach is particularly beneficial for absent students and those requiring additional learning support.
The proposed project focuses on designing an end-to-end automated system that integrates image acquisition, preprocessing, text extraction, document generation, and web-based hosting into a unified framework. The system aims to minimize manual intervention, improve the reliability of lecture note capture, and enhance the overall learning experience. By leveraging computer vision and document processing techniques, the project contributes toward scalable and cost-effective digital classroom solutions.

II. OBJECTIVES

The development of the proposed system is guided by clearly defined objectives focused on improving lecture content accessibility, accuracy, and digital availability within traditional classroom environments

2.1 Primary Objectives

The primary objective of this project is to automate the process of capturing and digitizing lecture notes written on classroom blackboards. By utilizing computer vision techniques, the system aims to reduce dependency on manual note-taking and ensure that lecture content is preserved accurately and consistently.
Another key objective is to enhance the quality of captured blackboard images through effective image preprocessing techniques such as noise reduction, thresholding, and perspective correction using OpenCV. These enhancements are intended to improve the reliability and accuracy of subsequent text extraction.
The system also aims to achieve efficient extraction of textual information from chalk-written content using Optical Character Recognition (OCR) techniques. Accurate text extraction is essential for converting visual lecture content into structured digital documents suitable for academic use.
Providing easy and continuous access to lecture notes is a core objective of the project. This is achieved by converting extracted content into Portable Document Format (PDF) files and hosting them on a web-based platform, enabling students to access lecture materials anytime and from any device.

2.2 Secondary Objectives

In addition to core functionality, the project aims to improve overall learning effectiveness by ensuring that students who miss classes due to absence or other constraints can still access complete lecture notes. This supports inclusive and flexible learning practices.
Another objective is to design a modular and scalable system architecture that can be extended in the future to support additional features such as handwritten equation recognition, diagram extraction, multilingual OCR, and cloud-based storage integration.
The system also seeks to minimize instructor involvement and classroom disruption by operating automatically with minimal manual intervention. Furthermore, the use of open-source technologies aims to provide a cost-effective solution suitable for deployment in educational institutions with limited resources.

III. LITERATURE REVIEW

3.1 Existing Solutions

The digitization of classroom lecture content has been an active area of research with the goal of improving knowledge retention, accessibility, and learning continuity. Early approaches focused on manual recording methods such as scanned handwritten notes or instructor-prepared digital slides. While these methods improved content availability, they introduced additional workload for instructors and failed to capture spontaneous explanations written on blackboards during lectures.

With advancements in computer vision, automated lecture capture systems have gained attention. Several studies have explored the use of camera-based systems to capture images of whiteboards or blackboards during classroom sessions. These systems typically rely on periodic image acquisition followed by image enhancement techniques to improve readability. Research indicates that raw classroom images often suffer from poor illumination, shadows, low contrast, and perspective distortion, which significantly degrade recognition accuracy if not properly handled.

Image preprocessing techniques using libraries such as OpenCV have been widely adopted to address these challenges. Techniques including grayscale conversion, adaptive thresholding, noise filtering, and geometric correction have been shown to significantly improve the quality of document images captured in uncontrolled environments [1], [4]. Studies emphasize that preprocessing is a critical stage for achieving acceptable Optical Character Recognition (OCR) performance in real-world classroom conditions.

Optical Character Recognition in Educational Applications

Optical Character Recognition has been extensively studied for converting printed and handwritten text into machine-readable formats [2], [3]. In educational contexts, OCR has been applied to digitize textbooks, handwritten notes, and examination scripts. However, chalk-written text on blackboards presents unique challenges due to irregular handwriting styles, uneven stroke thickness, background artifacts, and partial erasures.

Several researchers have demonstrated that OCR accuracy for handwritten or chalk-written text can be improved by combining robust image preprocessing with post-processing techniques such as spell correction and layout structuring. Despite these advancements, existing systems often focus on isolated OCR tasks and do not provide an end-to-end pipeline that captures, processes, formats, and distributes lecture content seamlessly.

Web-Based Document Access and Learning Support

Recent studies highlight the importance of web-based platforms for distributing academic resources. Hosting lecture materials online in standardized formats such as PDF improves accessibility, device compatibility, and long-term storage [6], [8]. Web-based access enables students to review lecture content at their own pace, supports revision during examinations, and assists students who miss classes due to unavoidable circumstances.

However, many existing lectures capture solutions lack proper integration between content extraction and content delivery. Systems often stop at text extraction without providing structured document generation or centralized access mechanisms. Literature emphasizes that effective educational digitization solutions must combine automated capture, reliable processing, and user-friendly access within a unified framework.

3.2 Research Gap

The literature review reveals a clear gap in the development of integrated systems that automatically capture blackboard lecture content and convert it into structured, accessible digital documents. Existing approaches either focus solely on image processing and OCR accuracy or emphasize content delivery without addressing the challenges of real-world classroom capture.

There is limited research on end-to-end systems that integrate computer vision–based image acquisition, preprocessing, OCR-based text extraction, PDF generation, and web-based hosting specifically for blackboard-centric teaching environments. Additionally, many existing solutions require significant manual intervention or specialized hardware, limiting their scalability and practical adoption.

The proposed project addresses this gap by presenting a complete, automated framework that captures blackboard lecture notes using computer vision techniques, converts them into structured PDFs, and hosts them on an accessible web platform. By leveraging open-source technologies and modular system design, the project aims to provide a scalable, cost-effective, and student-centric solution for digital lecture content management.

IV. PROPOSED SOLUTION

The proposed system provides an automated solution for capturing and digitizing classroom lecture notes written on blackboards. A camera-based module periodically captures images of the blackboard during lectures. These images are processed using computer vision techniques to enhance clarity and remove noise caused by lighting variations, shadows, and perspective distortion.

Image preprocessing is performed using OpenCV, including grayscale conversion, noise filtering, thresholding, and geometric correction to improve text visibility. Optical Character Recognition (OCR) is then applied to extract textual content from the processed images. The extracted text is organized and converted into Portable Document Format (PDF) files to ensure standardized storage and compatibility.

The generated PDFs are hosted on a web-based platform, allowing students to easily access, view, and download lecture notes anytime and from any device. The proposed solution minimizes manual effort, improves accessibility to academic content, and provides a scalable and cost-effective framework for digital lecture note management.

4.1 Core Features

4.1.1 Automated Blackboard Image Capture

The system automatically captures images of the classroom blackboard at regular intervals using a camera-based acquisition module, ensuring continuous and consistent recording of lecture content without instructor intervention.

4.1.2 Image Preprocessing and Enhancement

Captured images are enhanced using computer vision techniques implemented with OpenCV. Operations such as grayscale conversion, noise reduction, thresholding, and perspective correction improve image quality and text readability.

4.1.3 PDF Generation and Storage

Extracted lecture content is structured and converted into Portable Document Format (PDF) files. PDFs ensure standardized formatting, long-term preservation, and compatibility across multiple devices

4.1.4 Web-Based Access Platform

The generated lecture note PDFs are hosted on a web-based platform, allowing students to securely view, download, and manage lecture notes anytime and from any device.

4.1.5 Minimal Manual Intervention

The system operates with minimal human involvement, reducing instructor workload and eliminating the need for manual transcription or note compilation.

V. SYSTEM ARCHITECTURE

5.1 Architecture Overview

The proposed Blackboard Lecture Capture and Digital Repository System is designed using a layered and modular architectural framework to support automated content digitization, structured document generation, and scalable academic distribution. The architecture separates data acquisition, computational processing, document management, and user interaction into logically independent layers to ensure maintainability, extensibility, and reliable performance under varying classroom conditions.

At the foundational level, the image acquisition component captures blackboard content through a high-resolution camera system deployed within the classroom environment. This component is responsible for periodic or real-time image capture while maintaining adequate spatial alignment and visibility coverage. By isolating the acquisition module from processing logic, the architecture ensures flexibility in hardware configuration without affecting downstream computational modules.

The processing layer forms the core computational unit of the system and integrates computer vision techniques for image enhancement [1], [7]. Classroom environments typically introduce noise factors such as uneven illumination, shadows, chalk dust artifacts, and perspective distortion. To address these challenges, the architecture incorporates structured preprocessing operations including grayscale normalization, adaptive thresholding, noise filtering, edge enhancement, and geometric correction. This preprocessing stage significantly improves the robustness and reliability of subsequent text recognition tasks by generating a clean and standardized visual representation of board content.

Above the processing layer resides the text intelligence component, where Optical Character Recognition (OCR) algorithms convert enhanced image data into machine-readable text [2], [3]. This layer performs character segmentation, structural analysis, and contextual interpretation to reconstruct meaningful textual content from handwritten chalk inputs. Post-recognition refinement mechanisms improve textual coherence through formatting normalization and logical structuring. By encapsulating recognition logic within a dedicated layer, the architecture enables independent upgrades of OCR models without disrupting acquisition or distribution services.

The document management layer is responsible for transforming extracted textual data into structured digital artifacts. Recognized content is organized into formatted PDF documents with embedded metadata such as subject identification, lecture timestamp, and session indexing. Standardized naming conventions and archival structuring ensure systematic repository management and efficient retrieval. This abstraction of document generation into a separate module enhances long-term maintainability and supports integration with institutional content management systems.

The final layer consists of the web application and repository infrastructure, which provides controlled access to generated lecture materials. Backend services manage file storage, indexing, and request handling, while the presentation interface enables students to search, view, and download lecture notes through a structured digital repository. By separating presentation services from processing logic, the architecture supports scalable multi-user access and future integration with authentication or analytics systems.

Overall, the system operates as an integrated yet modular pipeline that transforms physical classroom board content into searchable digital documents through coordinated acquisition, vision-based enhancement, intelligent text extraction, structured document generation, and web-based distribution. The layered design promotes scalability across multiple classrooms, supports incremental technological upgrades, and ensures consistent performance under dynamic academic workloads [6], [8].

VI. IMPLEMENTATION METHODOLOGY

The implementation of the proposed Blackboard Lecture Capture and Digital Repository System follows a structured and system-oriented approach that translates computer vision and document digitization concepts into a functional academic automation framework. The methodology is designed to ensure high recognition accuracy, operational reliability, and seamless integration between image processing, text extraction, document generation, and web deployment modules. Each implementation stage incrementally refines the captured data to minimize error propagation and maintain consistency across the processing pipeline.

6.1 Image Acquisition and Calibration

The implementation begins with the deployment of a high-resolution camera system positioned to capture the complete blackboard surface during classroom sessions. Proper camera alignment and calibration are essential to ensure full board coverage while minimizing geometric distortion. The acquisition mechanism is designed to operate either in real-time or at predefined intervals, allowing systematic capture of lecture content without interrupting instructional flow.

Captured images are temporarily stored within a buffering mechanism before entering the processing pipeline. This staged handling ensures stability in data transmission and prevents frame loss during temporary processing delays. Environmental factors such as lighting conditions, board reflectivity, and instructor movement are considered during calibration to ensure consistent image quality across sessions.

6.2 Image Preprocessing and Enhancement

Classroom environments present several visual challenges, including uneven illumination, shadows, glare, chalk dust artifacts, and perspective distortions. To address these variations, the system implements a structured preprocessing framework using computer vision techniques [1], [4]. The primary objective of this stage is to standardize the captured image and enhance textual visibility before recognition.

The implementation performs grayscale normalization to simplify intensity variations and reduce computational complexity. Noise reduction techniques are applied to remove minor visual artifacts that may interfere with recognition. Adaptive thresholding enhances the contrast between chalk writing and the board background, ensuring that faint or partially erased characters remain detectable. Perspective correction algorithms compensate for angular distortion introduced during image capture, producing a geometrically aligned representation of the board surface. Additional contrast enhancement further improves clarity and uniformity across the image.

This preprocessing stage is critical to overall system performance, as OCR accuracy is strongly dependent on the quality and consistency of the processed input image.

6.3 Optical Character Recognition and Text Refinement

Following enhancement, the refined image is forwarded to the Optical Character Recognition (OCR) module, which forms the core intelligence component of the system. The OCR engine performs segmentation of textual regions, identifies character boundaries, and reconstructs lines of text into coherent digital form [2], [3].

Given the variability inherent in chalk-written content, including irregular spacing and stylistic differences, post-recognition refinement mechanisms are incorporated to enhance textual accuracy and readability. These mechanisms perform contextual correction, alignment normalization, and structural reconstruction to ensure that extracted content reflects the logical organization of the lecture. The objective of this stage extends beyond raw character extraction to generating academically usable textual data suitable for structured documentation.

6.4 Document Structuring and Digital Formatting

Once textual refinement is completed, the system transitions to document generation. The recognized content is organized into a standardized PDF format to ensure portability, consistency, and long-term archival stability. The implementation automatically embeds metadata elements such as subject name, lecture date, and session identification to facilitate systematic indexing and retrieval.

Formatting consistency is maintained through predefined structural templates that regulate heading alignment, paragraph organization, and page sequencing. Automated naming conventions ensure that generated documents are stored in a logically ordered manner within the repository. This stage ensures that the final output is not merely a text dump but a professionally structured lecture document suitable for academic reference.

6.5 Repository Integration and Web Deployment

The final implementation stage integrates generated PDF documents into a web-based repository system designed for structured access and efficient retrieval. Backend services manage file storage, metadata indexing, and request handling, while the front-end interface enables students to search, view, and download lecture materials based on subject or date.

The repository architecture is designed to support scalability across multiple classrooms and long-term archival requirements. Secure access mechanisms ensure controlled distribution of academic content, while optimized indexing structures enable rapid search operations. By separating processing logic from user interaction services, the implementation maintains system modularity and supports future integration with authentication or analytics modules.

VII. BENEFITS AND IMPACT

This section discusses the broader academic, institutional, and societal impact of the proposed Blackboard Lecture Capture and Digital Repository System. While previous sections focus on system design and implementation, the emphasis here is on how the solution transforms traditional classroom practices into a structured and accessible digital learning ecosystem. By integrating automated image processing, text digitization, and web-based dissemination, the system delivers value at multiple levels of the educational infrastructure.

7.1 Benefits for Students

The primary beneficiaries of the system are students, particularly those who face challenges in manual note-taking due to fast-paced teaching, visibility limitations, or absence from lectures. By automatically converting blackboard content into structured PDF documents, the system reduces cognitive load and allows students to focus on conceptual understanding rather than transcription. The availability of organized digital lecture notes improves revision efficiency and supports long-term knowledge retention. Students can revisit archived materials at any time, enabling self-paced learning and reinforcing classroom instruction. The searchable repository further enhances accessibility by allowing retrieval of lecture content based on subject or date, thereby improving academic organization.

In addition, the system supports inclusivity by assisting students with handwriting difficulties, visual limitations, or learning constraints. By ensuring consistent documentation of lecture content, the platform promotes equitable access to academic resources.

7.2 Benefits for Faculty

For instructors, the system eliminates the need to manually distribute notes or repeat content for absent students. Since lecture materials are automatically archived, faculty members can focus more on interactive teaching and concept clarification rather than content repetition.

The digital preservation of board content also enables faculty to maintain a documented record of course progression. This structured archival capability supports syllabus tracking, academic audits, and curriculum planning. Over time, accumulated lecture repositories can serve as reusable academic resources for future teaching sessions.

7.3 Contribution to Digital Education Ecosystem

The proposed system aligns with broader digital transformation initiatives in education by integrating automation, computer vision, and web-based accessibility into conventional teaching methodologies. It demonstrates how intelligent document digitization can enhance learning continuity without disrupting existing classroom practices.

By converting physical board content into structured digital knowledge assets, the system contributes to sustainable and scalable digital learning models. It reduces dependency on manual transcription, minimizes information loss, and promotes organized academic documentation. Over time, such systems can form the foundation for advanced analytics, automated content indexing, and integration with e-learning platforms.

VIII. CHALLENGES AND LIMITATIONS

8.1 Technical Challenges

One of the primary technical challenges relates to variability in classroom lighting and board conditions. Uneven illumination, glare from reflective board surfaces, shadows caused by instructor movement, and chalk dust artifacts can significantly affect image quality. Although preprocessing techniques mitigate many of these issues, extreme environmental conditions may still degrade recognition accuracy.

Another major challenge involves the inherent variability of handwritten chalk text. Differences in writing style, stroke thickness, spacing irregularities, and partially erased content introduce complexities for Optical Character Recognition systems [2]. Unlike printed text, chalk writing lacks uniformity, making consistent character segmentation and recognition difficult. While post-processing techniques improve textual coherence, perfect recognition accuracy cannot always be guaranteed.

Computational performance is also a critical consideration. Image preprocessing and OCR operations are resource-intensive tasks [5], particularly when handling high-resolution images in real-time or across multiple classrooms simultaneously. Ensuring low processing latency while maintaining recognition accuracy requires optimized algorithms and adequate hardware infrastructure.

8.2 Operational and Environmental Constraints

The system's performance is influenced by physical classroom setup and camera positioning. Improper camera alignment or incomplete board coverage may result in partial content capture. Additionally, dynamic classroom scenarios such as instructors standing in front of written content or rapid board erasures may lead to incomplete or blurred frames.

Network dependency presents another operational limitation, particularly in cloud-based deployments. Real-time transmission of images for processing requires stable internet connectivity [6], [8]. In environments with limited bandwidth, delays may occur in document generation and repository updates.

Furthermore, differences in board types (blackboard versus whiteboard), chalk contrast levels, and background coloration may impact preprocessing effectiveness. Adaptation mechanisms can mitigate these factors, but performance variations may still occur across different classroom settings.

8.3 Scalability and Deployment Limitations

Scalability introduces architectural challenges, particularly when expanding the system across multiple classrooms or institutions. Increased processing demand requires proportional scaling of computational resources and storage infrastructure. Without efficient load balancing and resource management strategies, performance bottlenecks may arise during peak academic hours.

Long-term archival management also presents storage considerations. Although PDF files require significantly less storage than video recordings, cumulative archival across semesters and departments necessitates structured storage optimization and periodic maintenance

IX. FUTURE SCOPE

9.1 Enhancement of Recognition Capabilities

Future development can focus on improving recognition accuracy for complex academic content, particularly mathematical equations, diagrams, tabular structures, and graphical representations. Advanced deep learning-based recognition models, such as convolutional neural networks and transformer-based vision architectures, may significantly enhance the system's ability to interpret non-linear and symbol-rich content [5].

Integration of specialized equation recognition engines could enable structured conversion of mathematical expressions into editable digital formats such as LaTeX. Similarly, diagram recognition frameworks may allow automatic reconstruction of flowcharts, graphs, and schematic illustrations. Such improvements would broaden the applicability of the system across science, engineering, and technical disciplines.

9.2 Multimodal Lecture Capture

An extended version of the system may integrate audio recording and speech-to-text conversion alongside board content extraction. By combining visual text recognition with instructor speech transcription, the system could generate comprehensive lecture summaries. This multimodal approach would capture both written and verbal instructional components, providing a more holistic academic record.

Further integration of classroom analytics, such as topic frequency analysis or concept mapping, could support academic performance evaluation and curriculum refinement.

9.3 Long-Term Vision

In the long term, the system may evolve into an intelligent classroom documentation platform capable of automated summarization, concept extraction, and adaptive content recommendation. Integration with artificial intelligence-driven tutoring systems could enable personalized revision materials based on extracted lecture content.

By continuously refining recognition accuracy, expanding repository intelligence, and integrating with broader educational technologies, the proposed system has the potential to contribute significantly to the development of smart digital classrooms and sustainable knowledge preservation infrastructures.

X. CONCLUSION

This paper presented a comprehensive Blackboard Lecture Capture and Digital Repository System designed to automate the transformation of traditional classroom board content into structured digital lecture documents. The motivation for this work stems from the limitations of manual note-taking practices, which often result in incomplete documentation, loss of instructional content, and reduced accessibility for absent or disadvantaged students. By integrating computer vision techniques, Optical Character Recognition (OCR), automated document generation, and web-based repository services, the proposed system provides a practical and scalable solution for modern academic environments.

A key contribution of this work lies in the development of a layered and modular architecture that ensures reliable image acquisition, robust preprocessing, accurate text extraction, structured document formatting, and efficient digital distribution. The implementation methodology demonstrates how environmental challenges such as lighting variations, perspective distortion, and handwritten inconsistencies can be mitigated through systematic preprocessing and post-recognition refinement mechanisms. Unlike traditional video-based lecture recording systems, the proposed approach focuses on generating lightweight, structured, and searchable PDF documents, thereby reducing storage overhead while enhancing usability.

From an academic perspective, the system improves learning continuity by preserving board-written instructional content in a permanent digital format. Students benefit from organized and accessible lecture archives that support revision and self-paced learning, while faculty members gain a structured documentation framework for course progression. At the institutional level, the solution contributes to digital transformation initiatives by bridging conventional chalkboard teaching with automated knowledge preservation technologies.

Although challenges remain in areas such as handwritten recognition variability and complex diagram extraction, the system establishes a strong foundation for future enhancements involving advanced deep learning models, semantic indexing, and multimodal lecture capture. The modular design ensures that individual components can evolve independently as recognition technologies and computational infrastructures advance.

In conclusion, the proposed system demonstrates the feasibility and effectiveness of automating classroom board digitization through an integrated computer vision and document management framework. By converting transient classroom content into structured digital knowledge assets, the system supports scalable, inclusive, and technology-enabled educational practices, contributing meaningfully to the development of intelligent digital classroom ecosystems.

REFERENCES

[1] Gonzalez, R. C., and Woods, R. E., Digital Image Processing, 4th ed. Pearson, 2018.

[2] Breuel, T. M., Ul-Hasan, A., Al-Azawi, M., and Shafait, F., "High-performance OCR for printed English and Fraktur using LSTM networks," in Proceedings of the International Conference on Document Analysis and Recognition (ICDAR), 2013, pp. 683–687.

[3] Smith, R., "An overview of the Tesseract OCR engine," in Proceedings of the International Conference on Document Analysis and Recognition (ICDAR), 2007, pp. 629–633.

[4] Jacobs, A. Z., and Ratner, A. J., "Document image preprocessing techniques for improved OCR performance," IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 40, no. 12, pp. 2998–3012, 2018.

[5] Goodfellow, I., Bengio, Y., and Courville, A., Deep Learning. MIT Press, 2016.

[6] Armbrust, M. et al., "Above the clouds: A Berkeley view of cloud computing," Communications of the ACM, vol. 53, no. 4, pp. 50–58, 2010.

[7] Castleman, K. R., Digital Image Processing. Prentice Hall, 1996.

[8] Marinescu, D. C., Cloud Computing: Theory and Practice. Morgan Kaufmann, 2013.