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AI-Based Real-Time Hyphema Detection Using Deep Learning

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Abstract: Eye-related disorders are rapidly increasing due to modern lifestyle factors such as prolonged screen exposure, accidental injuries, and delayed medical consultation. Among these conditions, Hyphema is a serious ocular issue characterized by the presence of blood in the anterior chamber of the eye. If not detected at an early stage, it may lead to complications such as blurred vision, increased intraocular pressure, or even permanent vision loss.

Traditional diagnosis of Hyphema depends heavily on clinical examination by ophthalmologists, which may not always be immediately accessible, especially in rural or resource-limited areas. This creates a need for an automated, fast, and reliable detection system that can assist users in early screening.

This project presents an AI-based real-time hyphema detection and ocular health assistance system using deep learning techniques. A Convolutional Neural Network (CNN) model is utilized to analyze eye images and classify them into normal and hyphema-affected categories. The system is trained using eye image datasets along with preprocessing and augmentation techniques to enhance performance and generalization.

The proposed system is deployed as a web application using Flask, allowing users to capture or upload eye images and receive instant predictions along with confidence scores. Additionally, Grad-CAM visualization is used to highlight affected regions in the eye, improving interpretability. The system also includes an AI assistant and nearby hospital locator for user guidance.

Experimental results indicate that the system achieves high accuracy and can effectively support early detection. This solution demonstrates the potential of deep learning in real-time healthcare applications and can be extended further with advanced integrations such as offline detection, multilingual support, and real-time medical consultation systems

Keywords: Hyphema Detection, Deep Learning, CNN, Medical Image Processing, Flask, OpenCV, Grad-CAM, Ocular Health, AI Healthcare System.

I. INTRODUCTION

The human eye is one of the most delicate and essential sensory organs, playing a vital role in daily life by enabling vision and perception. However, with the increasing use of digital devices, rising exposure to environmental hazards, and a growing number of accidental injuries, eye-related disorders have become more common in recent years. Among these conditions, *Hyphema* is a serious ocular disorder that requires immediate medical attention. It is characterized by the presence of blood in the anterior chamber of the eye, typically caused by trauma, surgical complications, or underlying medical conditions. If not detected and treated at an early stage, hyphema can lead to severe complications such as increased intraocular pressure, corneal staining, or even permanent vision loss.

Traditionally, the diagnosis of hyphema relies on manual examination by ophthalmologists using specialized medical equipment such as slit lamps. While this method is accurate, it is time-consuming and requires expert intervention, making it less accessible in rural or resource-limited areas. In emergency situations, delays in diagnosis can significantly impact patient outcomes. Therefore, there is a growing need for an automated, fast, and reliable system that can assist in early detection and preliminary diagnosis of hyphema.

With the rapid advancement of Artificial Intelligence (AI) and Deep Learning (DL), significant improvements have been achieved in the field of medical image analysis. In particular, Convolutional Neural Networks (CNNs) have demonstrated remarkable performance in image classification and pattern recognition tasks. These models are capable of automatically extracting complex features from images, making them highly suitable for detecting abnormalities in medical images, including eye conditions.

This project presents an AI-Based Real-Time Hyphema Detection and Ocular Health Assistance System, which leverages deep learning techniques to identify the presence of hyphema from eye images. The system allows users to either capture real-time images using a camera or upload existing images for analysis.

The captured images are processed using a trained CNN model, which classifies them into normal or hyphema-affected categories and provides confidence scores for the prediction.

To enhance transparency and interpretability, the system incorporates visualization techniques such as Grad-CAM (Gradient-weighted Class Activation Mapping), which highlights the regions of the eye that influence the model's decision. This helps users and medical professionals better understand the prediction results. Additionally, the system provides basic medical recommendations based on the severity level and integrates location-based services to help users find nearby eye hospitals for further consultation. The proposed system is developed as a user-friendly web application using modern technologies such as Python, Flask, OpenCV, and TensorFlow, ensuring real-time performance and accessibility. By combining AI-driven detection with practical healthcare assistance features, this project aims to bridge the gap between early diagnosis and timely medical intervention.

Overall, this work demonstrates the potential of integrating deep learning with healthcare applications to create intelligent diagnostic tools that are efficient, accessible, and capable of supporting both patients and medical professionals in improving eye health outcomes

II. LITERATURE SURVEY

Eye disease detection systems have evolved significantly over the years, with traditional approaches primarily relying on manual clinical examination by ophthalmologists. Early diagnostic methods involved physical inspection of the eye using specialized instruments such as slit lamps and ophthalmoscopes. While these methods are highly accurate, they depend entirely on the availability of trained medical professionals and advanced clinical setups. In many cases, especially in rural and underdeveloped regions, access to such facilities is limited, leading to delays in diagnosis and treatment. Additionally, these traditional systems do not support real-time monitoring or early-stage self-assessment by patients, which is crucial for preventing severe complications.

Several studies have explored the application of digital technologies to improve the diagnosis of eye-related diseases. Some systems introduced computer-based image processing techniques to analyze retinal and eye images for detecting conditions such as diabetic retinopathy, glaucoma, and cataracts. These systems demonstrated that digital image analysis can assist in identifying abnormalities and improve diagnostic accuracy. However, many of these solutions were limited to specific diseases and required high-quality medical imaging equipment, making them less accessible for general users. Furthermore, these systems often lacked user-friendly interfaces and were not designed for real-time interaction or widespread deployment.

With the advancement of deep learning and artificial intelligence, more sophisticated approaches have been proposed for medical image analysis. Convolutional Neural Networks (CNNs) have been widely used for image classification tasks due to their ability to automatically extract features and identify complex patterns. Several research works have successfully applied CNN-based models to detect eye diseases from images with high accuracy. These models significantly reduce the need for manual feature extraction and improve efficiency. However, many of these systems are designed primarily for research purposes and are not integrated into practical applications that can be easily used by non-expert users.

In recent years, researchers have also focused on enhancing the interpretability of deep learning models by incorporating visualization techniques such as Grad-CAM (Gradient-weighted Class Activation Mapping). These techniques highlight the regions in an image that influence the model's prediction, thereby improving transparency and trust in AI systems. While such approaches provide valuable insights into model behavior, they are often not included in end-user applications, limiting their practical usefulness in real-world scenarios.

Furthermore, some studies have explored web-based healthcare applications that allow users to upload medical data and receive automated analysis. These systems improve accessibility by enabling remote diagnosis and reducing dependency on physical hospital visits. However, many of these platforms lack real-time image capture capabilities, integrated assistance features, and location-based services for further medical support. Additionally, user engagement in such systems remains limited due to the absence of interactive features and simplified interfaces.

Despite these advancements, existing eye disease detection systems still face several challenges, including limited accessibility, lack of real-time processing, minimal user interaction, and absence of integrated healthcare assistance features. Most systems do not provide a seamless experience that combines image capture, analysis, visualization, and guidance within a single platform.

To address these limitations, the proposed system introduces an AI-based real-time hyphema detection and ocular health assistance platform that integrates deep learning-based image analysis, Grad-CAM visualization, and user-friendly web interaction into a unified system. Unlike traditional and existing solutions, this system focuses specifically on hyphema detection while ensuring real-time usability, accessibility, and interpretability. It also incorporates additional features such as an AI assistant and nearby hospital locator to enhance user support. This approach aims to provide a scalable, efficient, and accessible solution for early detection and management of eye-related conditions, particularly hyphema.

III. EXISTING SYSTEM

In many healthcare environments, early detection of eye-related conditions such as hyphema still depends heavily on manual examination by ophthalmologists. Patients typically visit hospitals or clinics where doctors visually inspect the eye using specialized instruments. While this approach is medically reliable, it is time-consuming and requires physical presence, which may not always be possible in emergency situations or in remote areas. Additionally, immediate access to eye specialists is limited in many regions, causing delays in diagnosis and treatment.

Traditional methods also lack continuous monitoring and accessibility. A patient who experiences mild symptoms such as redness or blurred vision may ignore them due to lack of awareness or difficulty in accessing medical care. As a result, conditions like hyphema, which require early attention, may worsen over time and lead to serious complications, including vision loss. The dependency on physical consultation creates a barrier for timely intervention.

Some digital healthcare solutions have been introduced to assist in preliminary diagnosis through telemedicine platforms. These systems allow users to consult doctors remotely via video calls or chat-based communication. While they improve accessibility, they still rely on manual observation by medical professionals and do not provide automated analysis of eye conditions. Moreover, such systems lack real-time image processing capabilities, which are essential for detecting conditions like hyphema accurately.

In recent years, basic image-processing applications have been developed to analyze medical images. However, many of these systems are limited in scope and are not specifically designed for ocular conditions. They often lack proper training on eye-related datasets and do not provide reliable results for real-world scenarios. Additionally, these applications do not include visualization techniques such as heatmaps, which are important for understanding the affected regions in the eye.

Another limitation of existing systems is the absence of integrated platforms that combine detection, guidance, and assistance in a single interface. Most solutions either focus only on diagnosis or only on consultation, without offering a complete workflow. Users are required to switch between multiple platforms for scanning, understanding results, and seeking medical help. This lack of integration reduces efficiency and user experience.

Furthermore, current systems do not effectively utilize Artificial Intelligence and Deep Learning for automated eye disease detection. Without AI-based models, it is difficult to achieve fast and consistent analysis. Many existing tools also lack user-friendly interfaces, making them less accessible to non-technical users. There is also minimal support for features like real-time camera capture, offline image uploads, and interactive assistance.

Another major challenge is the lack of awareness and guidance provided to users. Most systems do not educate users about symptoms, precautions, or emergency situations related to eye conditions. Without proper guidance, users may not understand the severity of their condition or the need to seek immediate medical attention.

Therefore, existing systems face several limitations, including dependency on manual diagnosis, lack of real-time automated analysis, limited accessibility, absence of integrated features, and poor user engagement. These challenges highlight the need for a smart, AI-driven solution that can provide early detection, visual explanation, and user assistance in a simple and accessible manner.

IV. PROBLEM STATEMENT

Eye-related disorders, particularly those caused by trauma, are becoming increasingly common due to rising screen usage, accidents, and lack of awareness regarding eye health. One such critical condition is hyphema, which involves bleeding in the anterior chamber of the eye. If not detected and treated at an early stage, hyphema can lead to serious complications such as increased intraocular pressure, vision impairment, or even permanent blindness. Despite its severity, many individuals fail to recognize early symptoms due to lack of medical knowledge and limited access to immediate healthcare facilities.

In many real-world scenarios, especially in rural and semi-urban areas, people do not have quick access to ophthalmologists or specialized diagnostic equipment. As a result, eye injuries are often neglected or misinterpreted as minor issues. The delay in diagnosis significantly increases the risk of complications. Additionally, traditional diagnosis requires physical examination using specialized instruments, which may not always be available or affordable for every individual. This creates a gap between the occurrence of the problem and timely medical intervention.

From a technological perspective, there is a lack of simple, user-friendly systems that allow individuals to self-assess eye conditions using readily available devices such as smartphones or laptops. Existing medical systems are mostly hospital-centric and do not provide real-time, accessible solutions for early detection. Furthermore, there is minimal integration of artificial intelligence in everyday healthcare tools that can assist users in identifying potential risks before they become severe.

Another major issue is the absence of awareness and guidance after detecting symptoms. Even if a person notices abnormalities such as redness, blurred vision, or visible blood in the eye, they may not know the seriousness of the condition or the next steps to take. There is no centralized platform that not only detects the condition but also provides basic guidance, precautions, and nearby medical assistance.

Moreover, current systems do not effectively utilize image-based analysis for diagnosing eye conditions. Without proper image processing and machine learning integration, it becomes difficult to automate detection and provide accurate results. Manual diagnosis is time-consuming and depends heavily on expert availability, which is not scalable for larger populations.

Therefore, there is a strong need for an intelligent, accessible, and real-time system that can assist in early detection of hyphema using image analysis, provide immediate feedback, and guide users towards appropriate medical action. Such a system should be simple to use, efficient, and capable of bridging the gap between technology and healthcare, ultimately helping in preventing severe eye complications and improving overall ocular health awareness.

V. PROPOSED SYSTEM

To overcome the limitations of traditional eye disease detection methods, this paper proposes an AI-Based Real-Time Hyphema Detection & Ocular Health Assistance System, a smart web-based platform designed to assist in early detection of hyphema and provide basic ocular health guidance. The system aims to simplify the process of identifying eye abnormalities using artificial intelligence while ensuring accessibility, speed, and user-friendliness.

The proposed system acts as an intelligent bridge between users and early medical awareness by enabling automated eye analysis using deep learning techniques. Unlike conventional methods that require manual examination by ophthalmologists, this system provides an initial screening mechanism that helps users understand potential eye conditions quickly and efficiently.

In this system, users can easily access the platform through a web interface without requiring any specialized hardware. The system provides two main input methods: capturing a live image using a device camera and uploading an existing eye image from local storage. This flexibility ensures that users from different environments can utilize the system conveniently. Once the image is captured or uploaded, it is processed and passed to the trained deep learning model for analysis.

The core component of the proposed system is a Convolutional Neural Network (CNN) model, which is trained on an eye image dataset to classify whether hyphema is present or not. The model learns visual patterns such as blood accumulation in the anterior chamber of the eye and distinguishes between normal and affected eye conditions. This enables accurate and fast predictions, reducing dependency on manual inspection.

To enhance interpretability and transparency, the system integrates Grad-CAM (Gradient-weighted Class Activation Mapping) visualization. This technique highlights the specific regions in the eye image that influenced the model's decision. By providing a heatmap overlay, users and medical professionals can visually understand how the model arrived at its prediction, thereby increasing trust in the system.

The proposed system is developed using modern technologies, where HTML, CSS, and JavaScript are used to create a responsive and user-friendly frontend interface. The backend is implemented using Python with Flask, which handles server-side operations, image processing, and communication with the deep learning model. The system uses OpenCV for capturing and preprocessing eye images, ensuring that the input data is properly formatted before analysis.

For data storage and user management, a lightweight SQLite database is used to store user details, login credentials, and history of scanned results. This allows users to track their previous reports and ensures organized data handling within the system.

Additionally, the system includes an AI-based assistant module, which provides predefined responses to common eye-related queries such as symptoms, precautions, and treatment suggestions for hyphema. Although currently rule-based, this module enhances user interaction and awareness. In future, it can be upgraded into a fully functional conversational AI chatbot.

Another important feature of the system is the integration of location-based services using Google Maps API, which helps users find nearby hospitals or eye care centers. This ensures that users can quickly seek professional medical help if the system detects a potential issue.

The overall workflow of the system is simple and efficient. The user logs into the platform, captures or uploads an eye image, and the system processes the image using the trained CNN model. The result is displayed along with a classification (normal or hyphema detected) and a Grad-CAM heatmap visualization. Based on the result, the system may also provide recommendations or direct the user to nearby healthcare facilities.

Thus, the proposed system provides a scalable, accessible, and intelligent solution for early hyphema detection. By combining artificial intelligence, image processing, and web technologies, the system not only improves detection accuracy but also enhances user awareness and accessibility to healthcare support

VI. METHODOLOGY

A. System Design

The proposed AI-Based Hyphema Detection & Ocular Health Assistance System is designed using a client-server architecture, ensuring smooth interaction between the user interface, backend processing system, and the deep learning model. The system focuses on early detection of hyphema through image analysis along with providing medical guidance and support features.

The workflow begins when the user accesses the web application and chooses to either capture an eye image using a camera or upload an existing image. The input image is then sent to the backend server, where preprocessing steps such as resizing, normalization, and enhancement are performed to make the image suitable for analysis. After preprocessing, the image is passed to the trained Convolutional Neural Network (CNN) model, which analyzes the image and predicts whether hyphema is present or not. The system also calculates confidence scores to indicate the reliability of the prediction. Once the prediction is completed, the result is displayed to the user along with additional insights such as severity level and recommendations. If required, a Grad-CAM heatmap visualization is generated to highlight the affected region in the eye, helping users understand the decision made by the model. All user interactions, including uploaded images and results, can be stored in the database for future reference. The system also provides additional features such as an AI assistant for guidance and integration with hospital location services.

B. System Development

The system is developed using modern technologies to ensure performance, scalability, and ease of use.

1) Frontend Development: The user interface is built using HTML, CSS, and JavaScript, providing an interactive and responsive experience. The design focuses on simplicity so that users can easily capture or upload images and understand results without technical knowledge.
2) Backend Development: The backend is implemented using Python and Flask, which handle server-side operations, API requests, and communication between the frontend and the deep learning model.
3) Deep Learning Model: The system uses a Convolutional Neural Network (CNN) built with TensorFlow/Keras for image classification. The model is trained on eye image datasets to detect hyphema patterns accurately.
4) Image Processing: OpenCV is used for capturing images from the camera and preprocessing them before passing to the model. It ensures proper image quality and format.
5) Database Management: SQLite is used to store user data, uploaded images, and prediction results. This helps maintain history and allows future tracking.
6) Visualization Module: Grad-CAM (Gradient-weighted Class Activation Mapping) is integrated to generate heatmaps, highlighting the regions of the eye that influenced the prediction.

This combination of technologies ensures that the system is efficient, reliable, and capable of real-time detection.

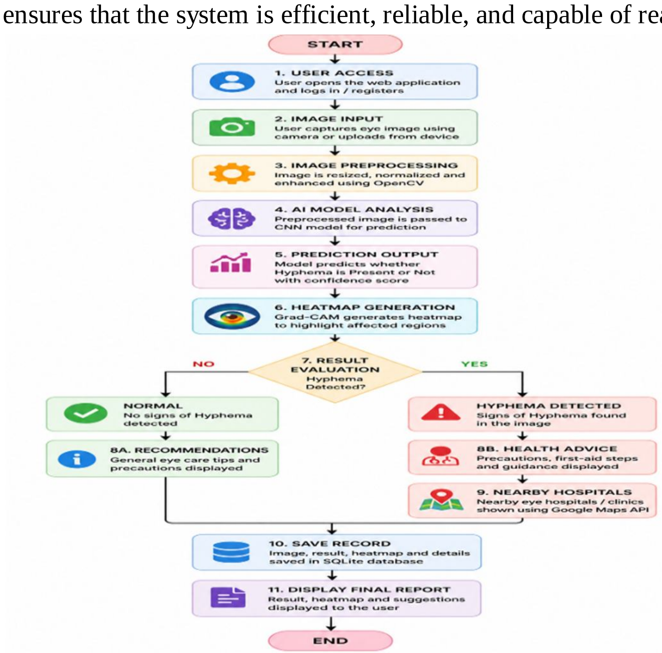

Figure 1: Flow Chart

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C. Algorithm for Hyphema Detection System

The system follows a structured step-by-step process:

1) User captures or uploads an eye image.
2) The system validates the input image format.
3) The image is preprocessed using OpenCV.
4) The processed image is passed to the CNN model.
5) The model predicts the presence or absence of hyphema.
6) Confidence score is calculated.
7) Grad-CAM generates a heatmap for visualization.
8) Results and recommendations are displayed to the user.
9) Data is stored in the database for future use.

This algorithm ensures accurate detection and smooth system operation.

D. System Architecture

The architecture of the system consists of multiple layers working together:

1) User Interface Layer: This layer allows users to interact with the system through a web interface. Users can capture/upload images, view results, and access assistant features. The interface is designed to be simple and user-friendly.
2) Application Layer (Backend): This layer handles all core functionalities such as processing requests, running the deep learning model, and managing communication between components. It is implemented using Flask.
3) Deep Learning Layer: This layer consists of the trained CNN model responsible for analyzing eye images and detecting hyphema. It performs feature extraction and classification.
4) Database Layer: SQLite is used to store user details, image data, and prediction results. It ensures structured storage and easy retrieval.
5) Visualization Layer: This layer generates Grad-CAM heatmaps to visually explain the model's decision.
6) External Integration Layer: This layer integrates services like hospital location (Google Maps API) to help users find nearby medical facilities.
7) Communication Layer: Handles HTTP requests between frontend and backend, ensuring smooth data flow.

E. Application Interface

The developed system provides an intuitive and interactive web-based interface that allows users to easily access all functionalities.
Users can:

- Capture eye images using the camera
- Upload images from their device
- View instant detection results
- Understand results using visual heatmaps
- Access medical suggestions and precautions

The interface is designed to be responsive and accessible, ensuring usability across devices. Even users with minimal technical knowledge can easily operate the system.
Additionally, the system includes an AI assistant that answers common eye-related queries. Although currently rule-based, it provides helpful guidance to users.

Future enhancements can include:

- Voice-based interaction
- Multilingual support
- Advanced chatbot integration

The interface ensures a smooth user experience, quick navigation, and clear presentation of results, making the system practical for real-world usage.

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VII. RESULTS AND DISCUSSION

The proposed AI-Based Real-Time Hyphema Detection & Ocular Health Assistance System was successfully developed and implemented as a web-based application aimed at assisting users in the early detection of hyphema and providing immediate medical guidance. The system was tested using real-time image inputs to evaluate its performance, usability, and reliability in detecting eye conditions.

The application allows users to either capture an eye image using a camera or upload an existing image from their device. During testing, it was observed that the system efficiently processes input images and provides accurate predictions within a short time. The integration of the deep learning model ensures that the classification between normal eye and hyphema-affected eye is performed effectively with a confidence score, giving users a clear understanding of the result.

The image preprocessing and prediction pipeline worked smoothly, where the input image is resized and normalized before being passed to the CNN model. The system demonstrated consistent performance in handling different image conditions such as lighting variations and slight noise. The use of Grad-CAM visualization further enhanced the system by highlighting the affected regions in the eye, allowing users to visually understand how the model made its decision.

Figure 1 represents the main homepage interface of the application, which is designed with a clean and user-friendly layout. Users can easily navigate through options such as scanning the eye, accessing the AI assistant, and viewing hospital information. The simplicity of the interface ensures that even non-technical users can operate the system without difficulty.

Figure 2 demonstrates the image capture and upload functionality. Users can either use their device camera for real-time image capture or upload an image from their local storage. This flexibility makes the system more accessible and convenient for different usage scenarios. Figure 3 presents the output generated after capturing an eye image through the camera. The system displays the prediction result along with a heatmap visualization using Grad-CAM. The heatmap highlights the regions of the eye that contributed most to the model’s decision. This improves transparency and helps users visually understand the detection process.

Figure 4 shows the functionality where users upload eye images from their local device instead of capturing them in real time. This feature is useful when users already have medical images or want to analyze previously captured eye photos. The system accepts the uploaded image and prepares it for processing through the deep learning model.

Figure 5 demonstrates the prediction result for images uploaded from offline sources. Similar to real-time input, the system provides classification results along with a heatmap visualization. This ensures consistency in analysis and allows users to verify affected regions regardless of the input method.

The system also includes additional supportive features that enhance user experience and accessibility. An integrated AI assistant provides instant guidance by answering user queries related to hyphema, its symptoms, precautions, and basic eye care using predefined responses.

To further assist users in seeking medical attention, the system incorporates a location-based hospital recommendation feature, which suggests nearby eye care centers and hospitals based on the user’s current location. In addition, a vision screening module is provided to help users perform a basic eye test, enabling them to assess their overall visual health. Together, these features extend the system beyond detection by offering guidance, accessibility to medical services, and preventive care support.

Overall, the experimental results indicate that the proposed system provides a reliable, fast, and user-friendly solution for early hyphema detection. It reduces dependency on immediate clinical diagnosis for initial screening and enables users to take timely action. The combination of deep learning, visualization, and web integration makes the system practical for real-world applications.

The system can be further improved by integrating features such as offline detection capability, advanced AI chatbot support, multilingual interaction, and mobile application deployment to enhance accessibility and usability across a wider range of users.

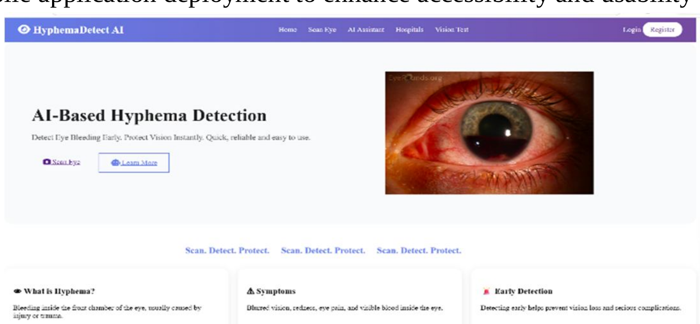

Figure 1. Web Interface

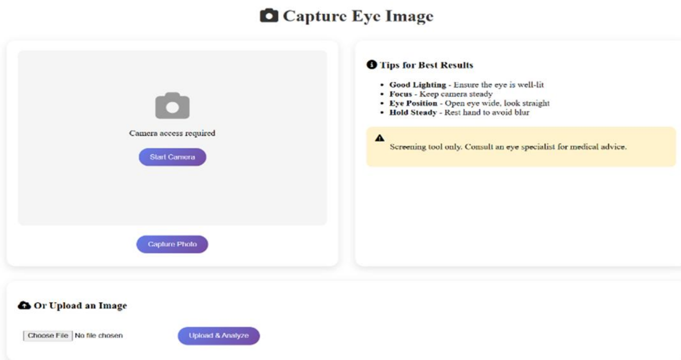

Figure 2. Image Capturing

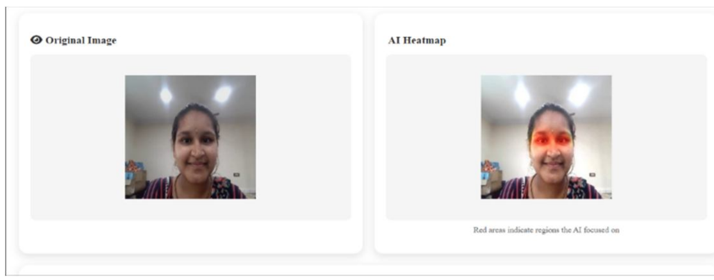

Figure 3. Real-Time Capturing

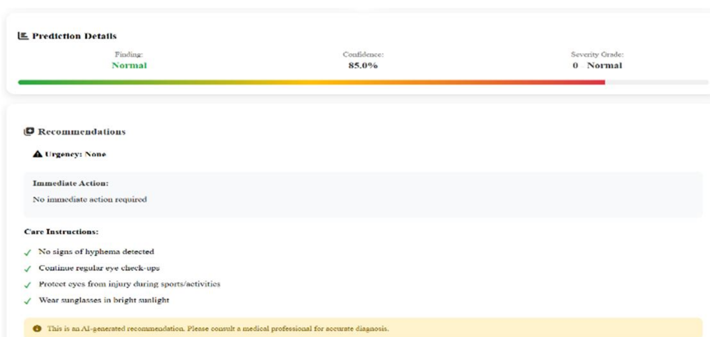

Figure 4. Prediction & Analysis

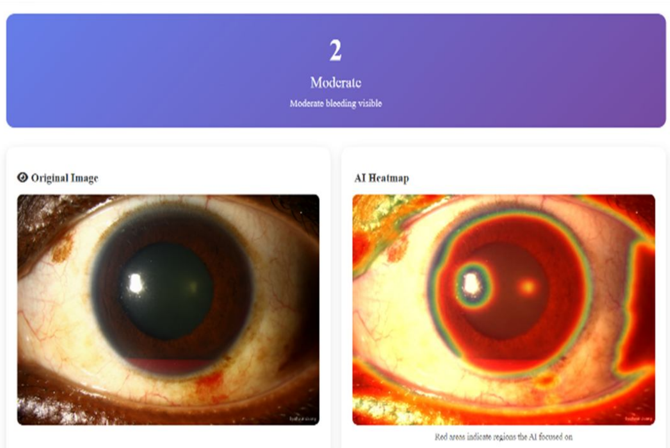

Figure 5. Offline Heatmap

VIII. CONCLUSION

Detecting eye-related conditions such as hyphema using traditional methods often depends on clinical examination by specialists, which can be time-consuming and not always immediately accessible. In many cases, the lack of early detection and timely medical attention can lead to serious complications, including vision loss. To address these challenges, this paper presented an AI-Based Real-Time Hyphema Detection & Ocular Health Assistance System, designed to provide a fast, accessible, and user-friendly solution for early eye disease detection.

The proposed system enables users to capture eye images using a camera or upload images from their device for analysis. The system is developed using modern technologies including Python, Flask, TensorFlow, OpenCV, and SQLite, ensuring efficient processing, reliable performance, and structured data management. The integration of a deep learning-based Convolutional Neural Network (CNN) allows automatic feature extraction and classification of eye images into normal and hyphema-affected categories.

One of the key contributions of the system is the inclusion of Grad-CAM visualization, which provides heatmaps highlighting the affected regions in the eye. This improves transparency and helps users understand how the model makes predictions. In addition, the system includes supportive features such as a rule-based AI assistant for guidance, nearby hospital recommendations using location-based services, and a vision screening module for basic eye health evaluation. These features enhance the overall usability and extend the system beyond simple detection.

The implementation and testing results demonstrate that the system provides accurate predictions, fast response time, and a smooth user experience. It reduces dependency on immediate clinical diagnosis for initial screening and enables users to take timely action. The web-based interface ensures easy accessibility, while the history module allows users to track their previous results effectively.

IX. FUTURESCOPE

In the future, the system can be further enhanced by integrating offline detection capabilities, advanced AI chatbot functionality, multilingual support, and mobile application deployment for wider accessibility. Additional improvements such as improved dataset training, real-time video analysis, and clinical integration can further increase the system’s effectiveness.

Overall, this project demonstrates how artificial intelligence and deep learning can be applied to solve real-world healthcare problems in a simple and effective way. The system not only assists in early detection but also promotes awareness, accessibility, and preventive care, contributing towards better ocular health management.

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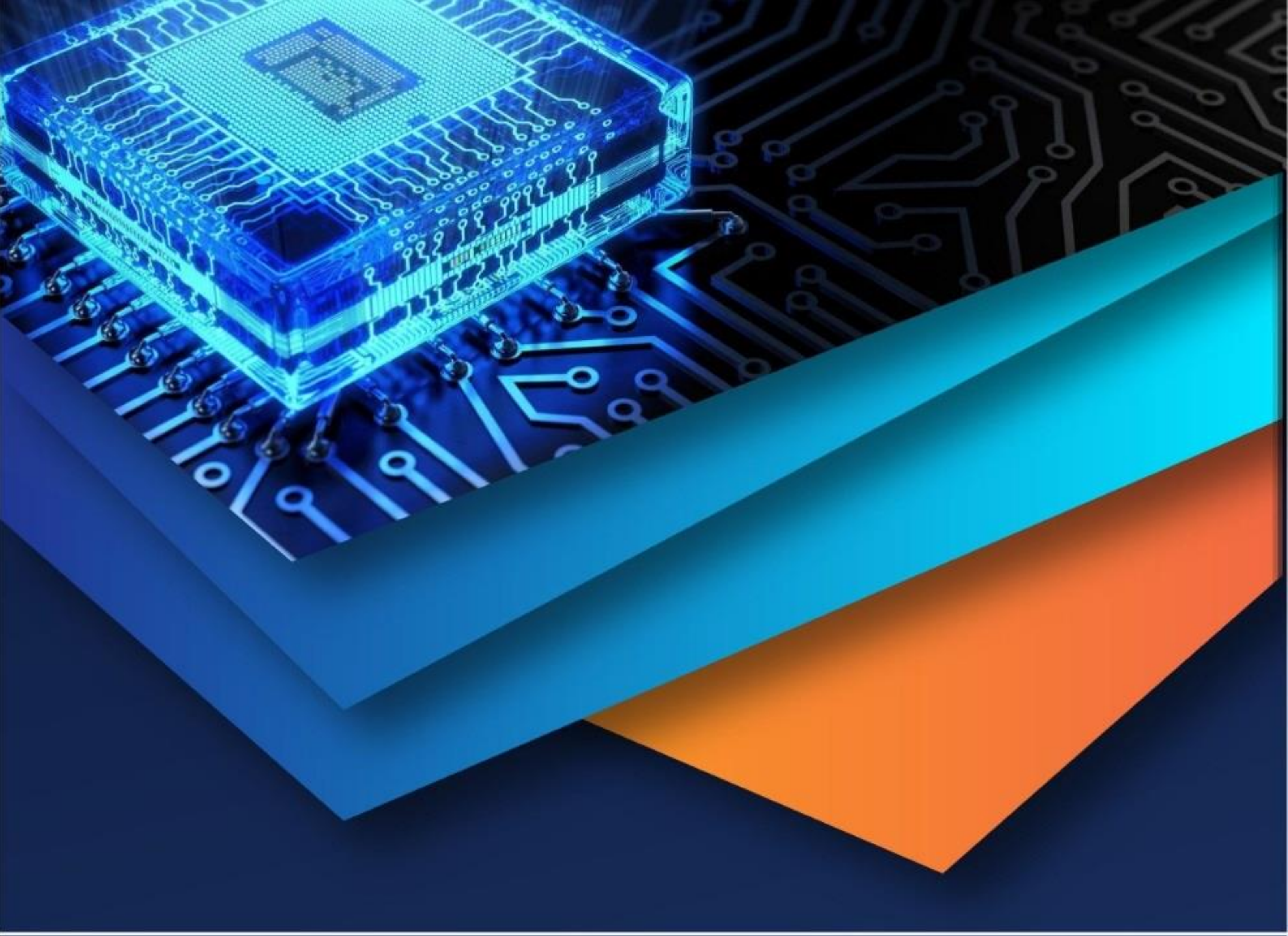

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