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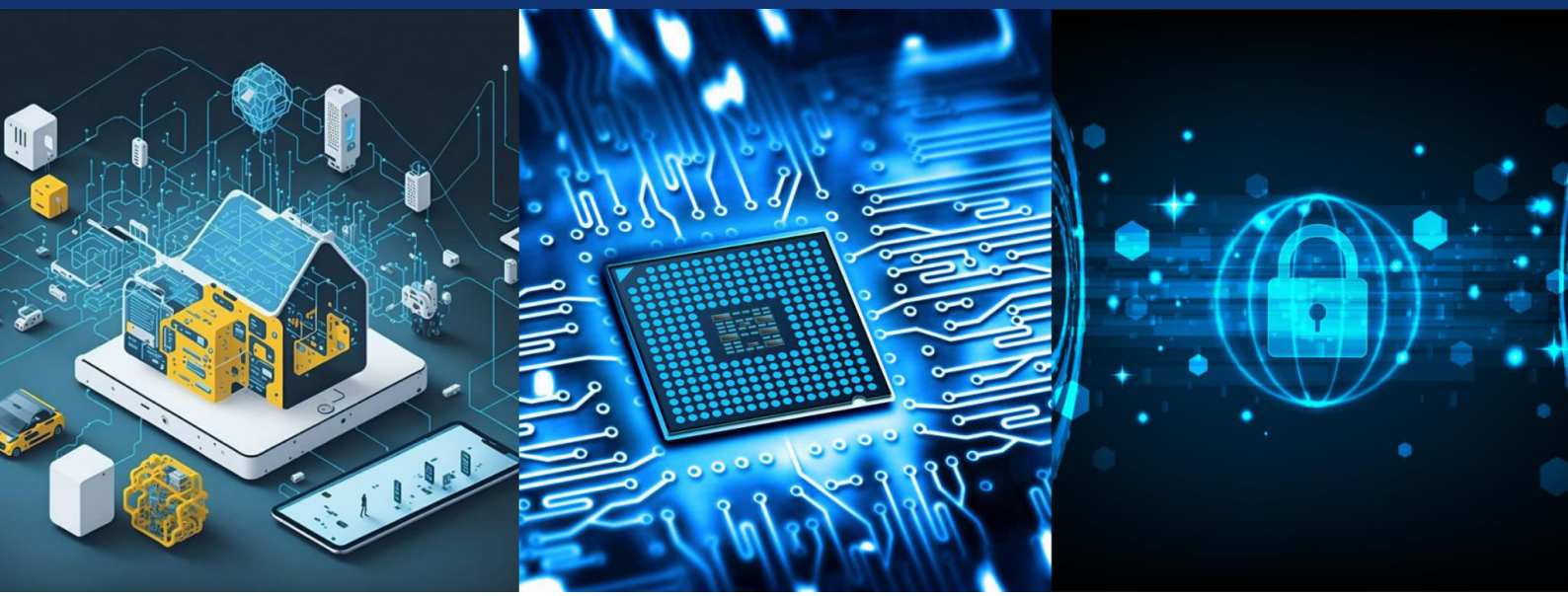

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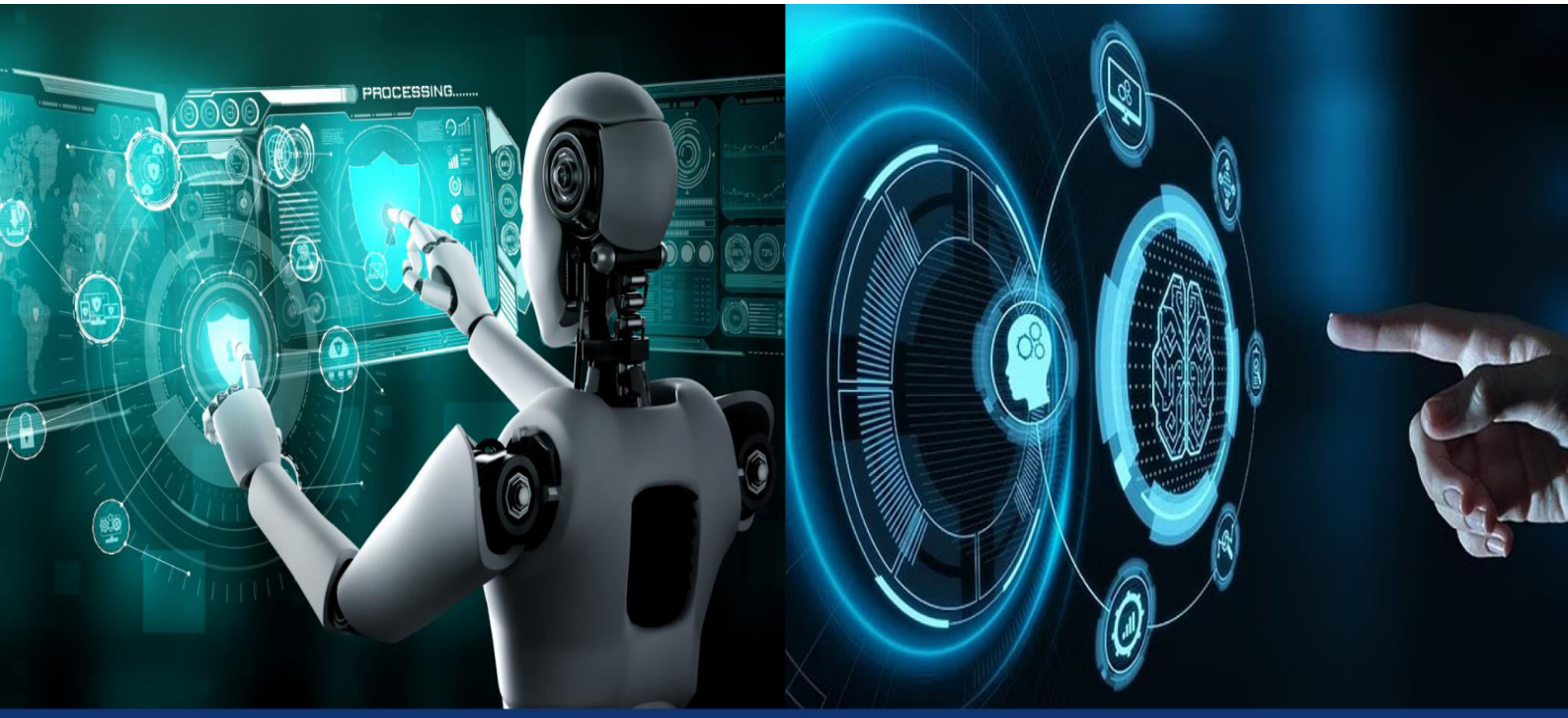

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AI Based Bone Marrow Disorder Prediction Using Deep Learning

Keerthana T C, Yashaswini J

IV Semester MCA, Dept. of DoS in Computer Science, PG Wing of SBRR Mahajana First Grade College (Autonomous), Mysuru, India

Assistant Professor, Dept. of DoS in Computer Science, PG Wing of SBRR Mahajana First Grade College (Autonomous), Mysuru, India

ABSTRACT: Bone marrow disorders such as Aplastic Anemia, Leukemia, Lymphoma, and Myelodysplastic Syndrome (MDS) are serious haematological diseases that require early and accurate diagnosis for effective treatment. Traditional diagnosis through microscopic examination is time-consuming, labor-intensive, and highly dependent on the expertise of hematologists. To address these challenges, this project presents an AI-Based Bone Marrow Disorder Detection System using deep learning techniques for automated disease classification and explainable diagnosis. The proposed system utilizes the YOLOv8 Classification model to classify bone marrow microscopic images into five categories: Aplastic Anemia, Leukemia, Lymphoma, Myelodysplastic Syndrome (MDS), and Normal. Before classification, the images are pre-processed through resizing and normalization to improve model performance. The trained model predicts the disease class and generates confidence scores for each category, enabling reliable and accurate diagnosis. To enhance the interpretability of the model, the system integrates ResNet18-based Multi-layer Grad-CAM++, which generates heatmaps highlighting the important regions of the image responsible for the prediction. These visual explanations help healthcare professionals understand the model's decision-making process and increase confidence in AI-assisted diagnosis. The proposed system aims to reduce diagnosis time, improve diagnostic accuracy, minimize human error, and support haematologists in clinical decision-making. It serves as an effective AI-assisted clinical decision-support tool for the early detection and classification of bone marrow disorders.

KEYWORDS: Bone marrow disorder detection, YOLOv8 classification, Deep learning, medical image analysis, Grad-CAM++, ResNet18, Explainable artificial intelligence (XAI), Clinical decision support system.

I. INTRODUCTION

Bone marrow is a vital tissue responsible for the production of blood cells that are essential for oxygen transport, immunity, and blood clotting. Diseases affecting the bone marrow, such as Aplastic Anemia, Leukemia, Lymphoma, and Myelodysplastic Syndrome (MDS), can significantly impair normal blood cell formation and may become life-threatening if not diagnosed at an early stage. Accurate identification of these disorders is therefore essential for timely treatment and improved patient outcomes [5], [13]. Advances in deep learning have created new opportunities for automated medical image analysis by enabling computers to recognize complex cellular patterns with high precision. AI-based diagnostic systems can assist pathologists by reducing manual effort, improving consistency, and providing rapid analysis of bone marrow microscopic images [2], [9], [10].

This research paper presents an AI-based bone marrow disorder detection system using the YOLOv8 Classification model to classify bone marrow microscopic images into five categories. ResNet18-based Multi-layer Grad-CAM++ provides visual explanations through heatmaps, while a Gradio-based GUI displays predictions, confidence scores, and visualizations. The proposed framework offers an accurate, efficient, and explainable solution for AI-assisted bone marrow disorder diagnosis [7], [14], [18], [19], [20].

The main objectives of this research are:

- To develop an AI-based system for automatic detection of bone marrow disorders using deep learning.
- To implement ResNet18-based Multi-layer Grad-CAM++ for explainable visual heatmaps.
- To develop a Gradio-based GUI for image upload, disease prediction, and result visualization.

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- To provide explainable AI outputs that support clinical decision-making.
- To assist in the early detection of bone marrow disorders for timely diagnosis and treatment.

II. RELATED WORK

2.1 Conventional Bone Marrow Disorder Diagnosis

The traditional diagnosis of bone marrow disorders relies on microscopic examination of bone marrow smear images by experienced hematologists and pathologists. Although this method is considered the clinical standard, it is time-consuming, labor-intensive, and subject to inter-observer variability. These limitations have motivated the development of automated computer-aided diagnosis systems based on medical image analysis.

2.2 Deep Learning-Based Approaches

Recent studies have demonstrated the effectiveness of deep learning in the automated analysis of bone marrow microscopy images. Acevedo et al. [1] introduced a large-scale bone marrow cell image dataset for morphological classification, providing a valuable benchmark for developing AI-based diagnostic systems. Matek et al. [2] proposed a deep learning model for the recognition of blast cells in acute myeloid leukemia, achieving human-level performance and demonstrating the potential of AI-assisted hematological diagnosis.

Rehman et al. [3] developed a deep learning framework for automated leukemia detection from microscopic images, showing that convolutional neural networks can effectively extract disease-specific features. Similarly, Zhang et al. [4] and Li et al. [7] employed YOLO-based models for medical image analysis, demonstrating accurate and efficient detection of abnormal cells with reduced computational complexity.

Recent research has also focused on improving the interpretability of AI-based diagnosis. Lv et al. [11] proposed a deep learning system for high-accuracy morphological identification of bone marrow cells, while Alshahrani et al. [12] developed an attention-based transfer learning model for the diagnosis of hematological disorders. Furthermore, van Eekelen et al. [14] highlighted the importance of Explainable Artificial Intelligence (XAI) in bone marrow histological diagnosis, emphasizing that visual interpretation techniques can improve clinicians' confidence and support the adoption of AI in clinical practice.

2.3 Explainable Artificial Intelligence

To improve the transparency of deep learning models, Explainable Artificial Intelligence (XAI) techniques have been increasingly adopted in medical image analysis. Grad-CAM and its improved variant Grad-CAM++ generate heatmaps that highlight the image regions influencing the model's predictions, enabling clinicians to better understand and validate AI-assisted diagnostic decisions [19]. The effectiveness of these visualization techniques is further enhanced when combined with deep learning architectures such as ResNet, which provides robust feature extraction through residual learning [18]. Recent studies have also emphasized that integrating explainable AI into bone marrow diagnosis improves the reliability, transparency, and clinical acceptance of deep learning-based decision support systems [14].

2.4 Summary of Identified Research Gaps

Although existing studies have achieved promising results in bone marrow image classification, many focus on a single disorder or lack visual interpretability. Few systems combine accurate multi-class classification with explainable AI in an interactive application. To address these limitations, the proposed system integrates YOLOv8 Classification for five-class bone marrow disorder classification with ResNet18-based Multi-layer Grad-CAM++ for visual explanations. A Gradio-based GUI further enables real-time prediction, confidence score visualization, and explainable diagnosis, making the system suitable for AI-assisted clinical decision support.

III. MATERIALS AND METHODS

3.1 Dataset

Bone marrow microscopy image dataset consisting of five diagnostic categories: Aplastic Anemia, Leukemia, Lymphoma, Myelodysplastic Syndrome (MDS), and Normal. The dataset contains approximately 2,300 Aplastic Anemia, 2,000 Leukemia, 1,000 Lymphoma, 1,000 MDS, and 1,000 Normal images, representing diverse bone marrow cell morphologies. The dataset is partitioned into 80% training and 20% testing subsets. The training dataset is used to

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learn disease-specific features, whereas the testing dataset evaluates the model's classification performance on previously unseen images.

3.2 Image Pre-processing

Before classification, the uploaded bone marrow microscopic images are validated using an Out-of-Distribution (OOD) detection module to ensure that only valid bone marrow images are processed. The validated images are then pre-processed by resizing them to the required input size and applying normalization to improve image quality and ensure consistent model performance.

3.3 Feature Extraction

The pre-processed bone marrow microscopy images are automatically processed by the YOLOv8 Classification model to extract high-level discriminative features. The convolutional layers learn important morphological characteristics such as cell shape, size, texture, nucleus appearance, and staining patterns without requiring manual feature engineering. These extracted deep features are then used to classify the images into one of the five diagnostic categories.

3.4 Classification Model

The pre-processed images are classified using the YOLOv8 Classification model. The model automatically extracts discriminative features and classifies each image into one of five diagnostic categories: Aplastic Anemia, Leukemia, Lymphoma, Myelodysplastic Syndrome (MDS), or Normal. The prediction results include the disease label, confidence score, and class probabilities.

3.5 Explainable AI

ResNet18-based Multi-layer Grad-CAM++ to improve the interpretability of the YOLOv8 Classification model. Grad-CAM++ generates heatmaps that highlight the important regions of the bone marrow image responsible for the predicted disease. These visual explanations help clinicians understand, verify, and trust the model's predictions, thereby improving the transparency and reliability of AI-assisted bone marrow disorder diagnosis.

3.6 Experimental Setup

The proposed framework is implemented using Python, PyTorch, Ultralytics YOLOv8, OpenCV, NumPy, Pillow, Gradio, and Grad-CAM++ libraries. Model performance is evaluated using classification accuracy, confidence scores, and Grad-CAM++ visualizations on the testing dataset.

3.7 System Architecture

The System Architecture Diagram illustrates the complete workflow of the AI-Based Bone Marrow Disorder Detection System. It shows how a bone marrow microscopic image is processed using deep learning models to identify disorders, generate an explainable heatmap, and present the results to the user.

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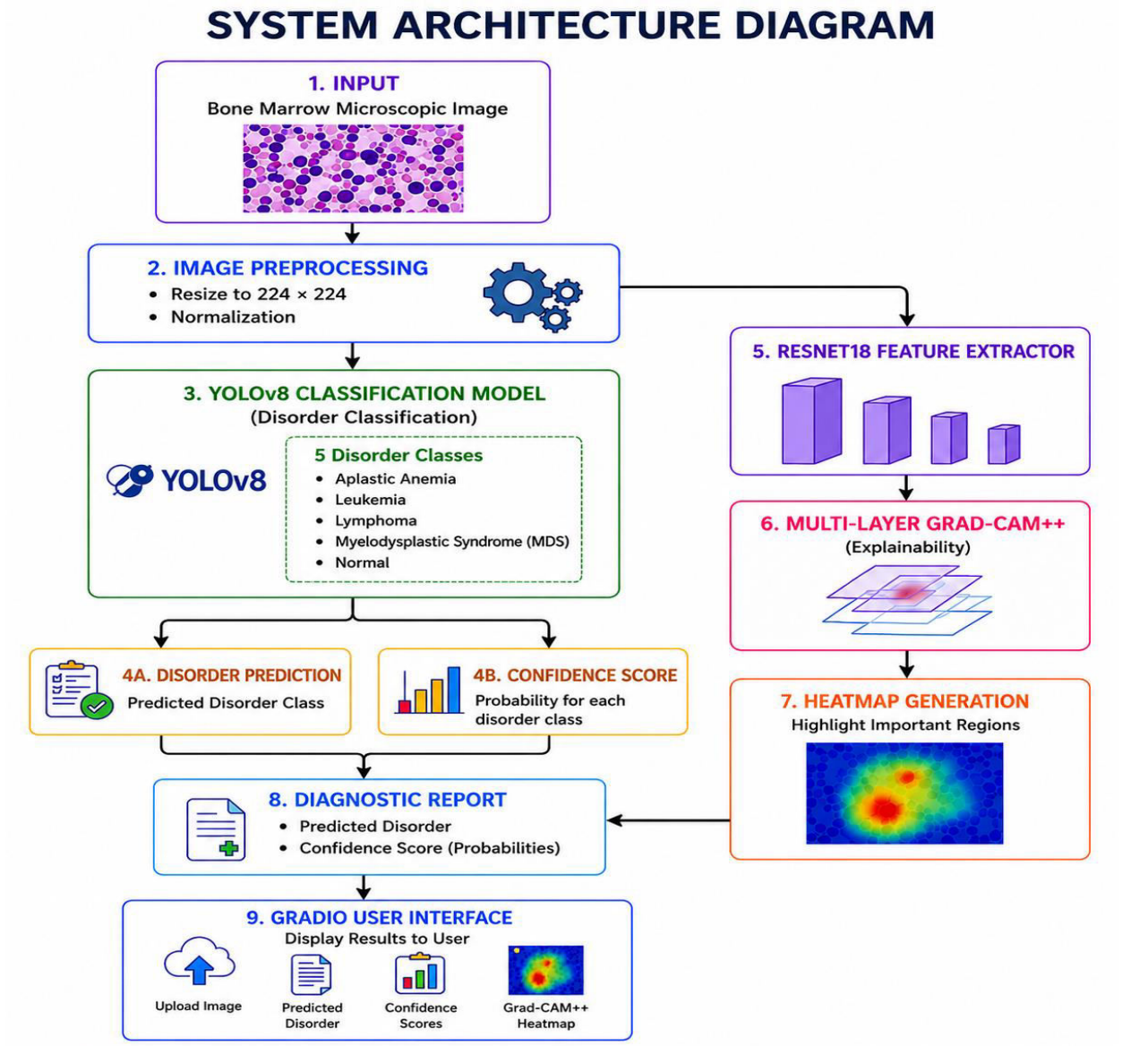

Figure 1: System Architecture Diagram for AI based Bone Marrow Disorder Prediction System

The proposed architecture enables efficient and automated analysis of bone marrow microscopic images for disease classification. The modular framework performs image preprocessing, YOLOv8-based classification, ResNet18-based Multi-layer Grad-CAM++ visualization, and diagnostic report generation through an interactive Gradio-based graphical user interface (GUI). The modular design allows each stage to operate independently, making the system accurate, scalable, explainable, and suitable for AI-assisted clinical decision support.

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IV. RESULTS AND DISCUSSION

4.1 Prediction Interface

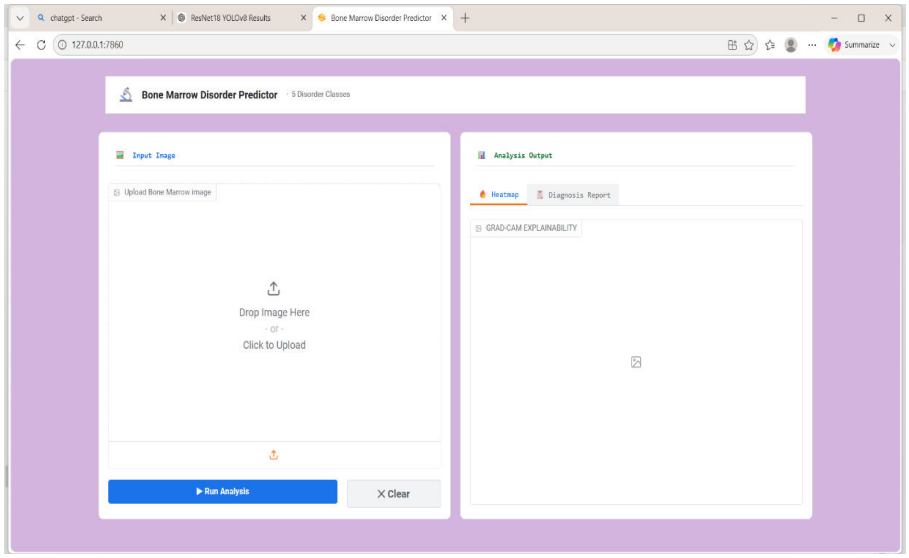

Figure 2: Prediction Interface of Bone Marrow Disorder

The Bone Marrow Disorder Prediction system provides a simple and user-friendly interface for disease detection. Users can upload a bone marrow microscopic image and start the analysis using the Run Analysis button. The interface displays the Grad-CAM++ heatmap and a diagnosis report containing the predicted disease, confidence score, and class probabilities, providing an explainable AI-assisted diagnosis

4.2 Prediction Output

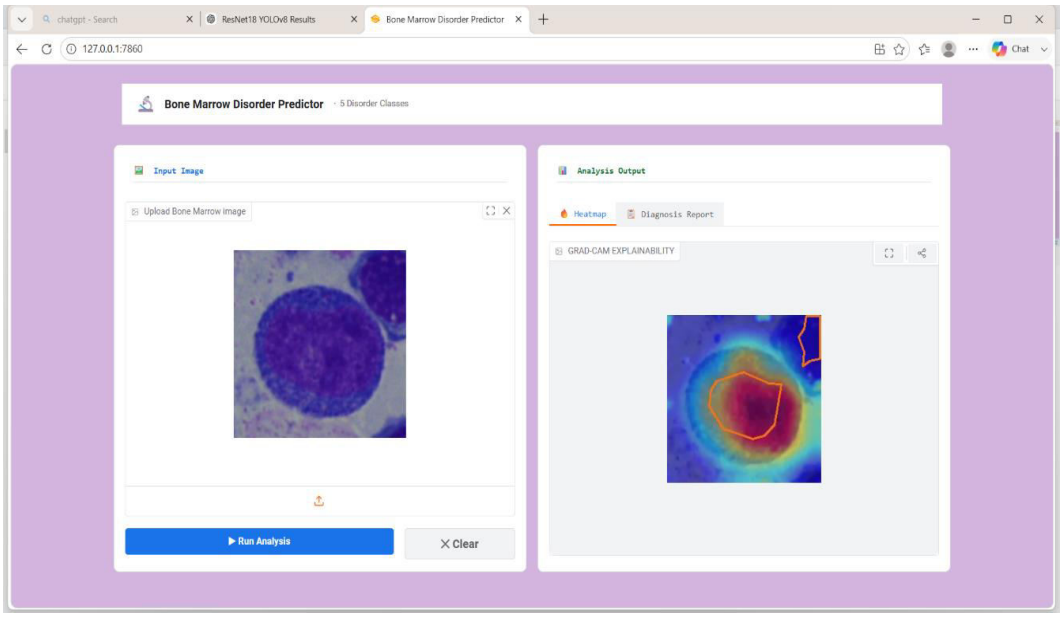

Figure 3: Bone Marrow Disorder Grad-CAM++ Explainability

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The Grad-CAM++ heatmap highlights the important regions of the uploaded bone marrow image that contribute to the prediction. The highlighted regions help clinicians understand the model's decision, improving the transparency and reliability of the diagnosis.

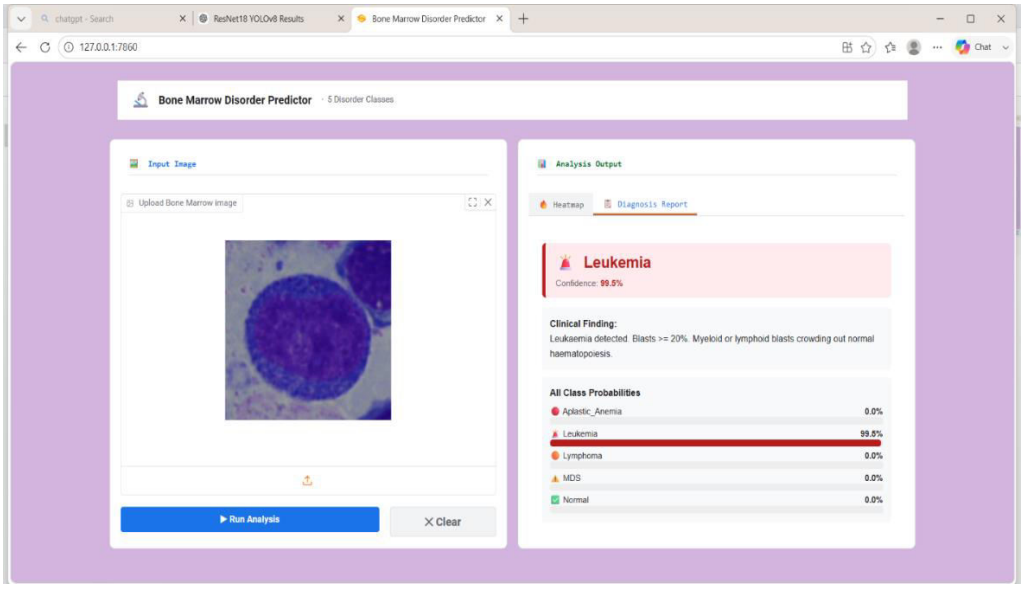

Figure 4: Bone Marrow Disorder Prediction Output

The diagnosis report displays the predicted disease, confidence score, and probabilities of all five disease classes. It also includes clinical findings, enabling clinicians to quickly interpret the prediction and assess the model's confidence in the diagnosis.

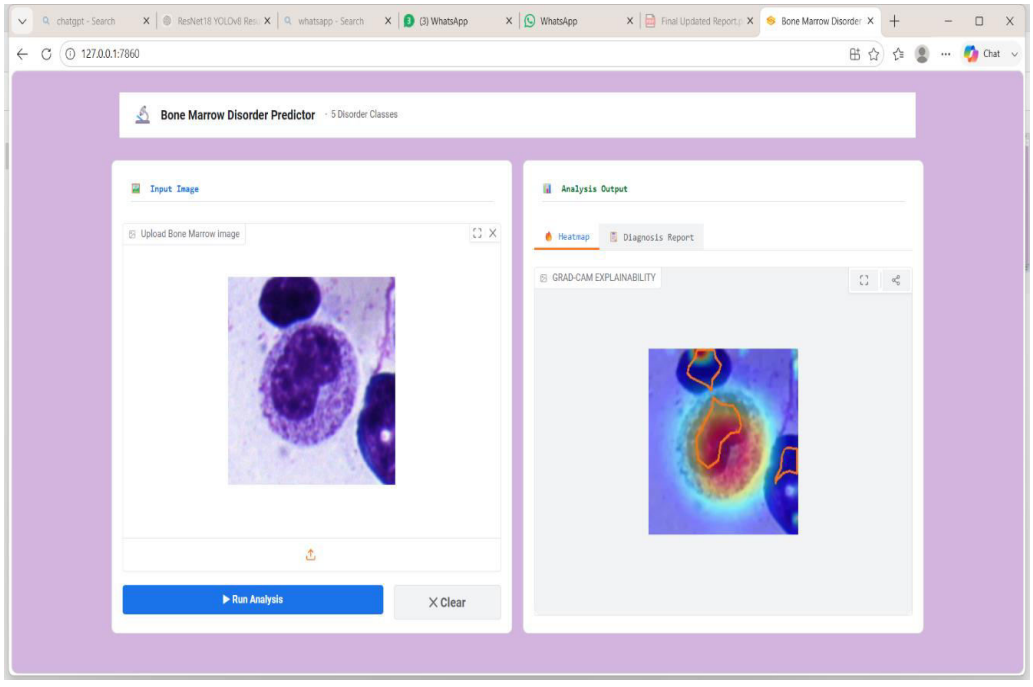

Figure 5: Grad-CAM++ result

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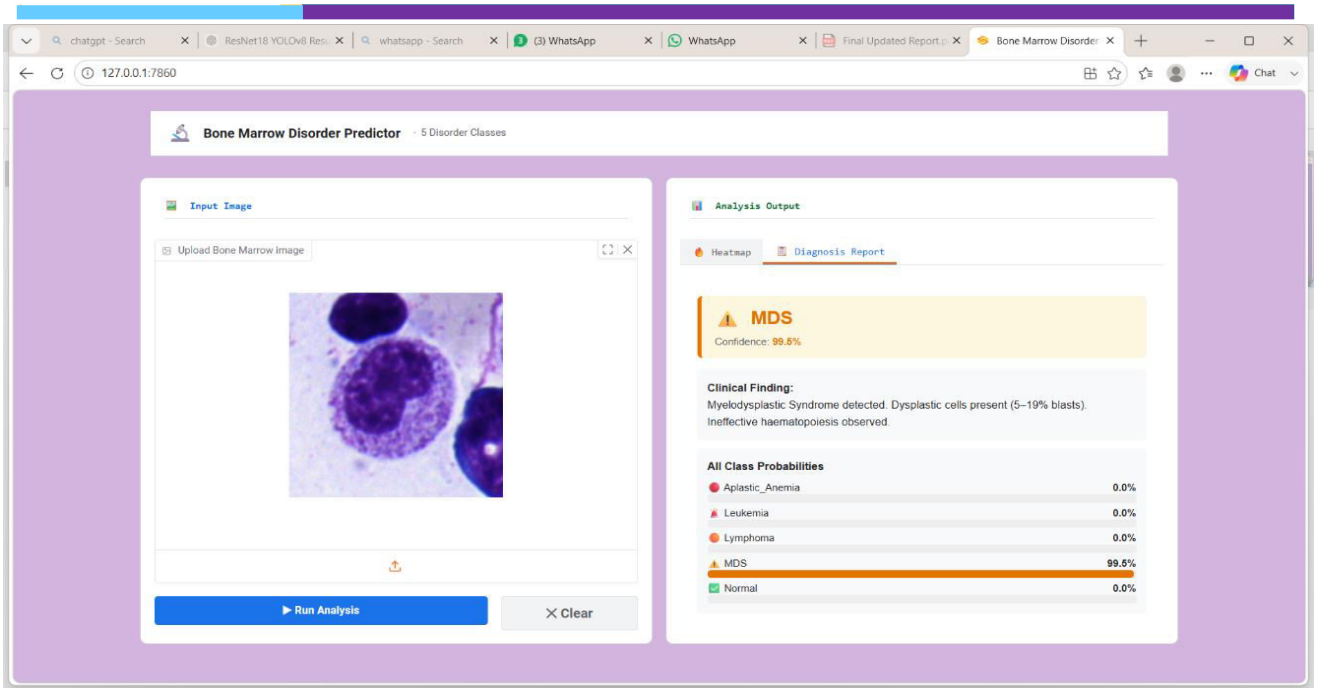

Figure 6: Myelodysplastic Syndrome Bone Marrow Disorder

V. CONCLUSION AND FUTURE WORK

This paper presented an AI-based bone marrow disorder prediction system for the automated classification of bone marrow microscopic images into five categories: Aplastic Anemia, Leukemia, Lymphoma, Myelodysplastic Syndrome (MDS), and Normal. The proposed framework combines the YOLOv8 Classification model for efficient disease classification with a pretrained ResNet18 model to generate Multi-layer Grad-CAM++ visualizations, improving the interpretability of the prediction process. An Out-of-Distribution (OOD) detection module is incorporated to validate uploaded images before classification, thereby enhancing the reliability of the system. In addition, image processing techniques are employed for bone marrow cell segmentation, and a Gradio-based graphical user interface (GUI) provides an interactive platform for image upload, prediction, confidence score visualization, heatmap generation, and diagnostic reporting. The proposed system demonstrates the potential of deep learning as an effective clinical decision-support tool by reducing manual effort, improving diagnostic consistency, and assisting hematologists in the early detection of bone marrow disorders.

Future work will focus on expanding the dataset with multi-center clinical data to improve the robustness and generalization of the model. The system can be extended to classify additional bone marrow disorders and rare hematological diseases by incorporating larger and more diverse datasets. Advanced deep learning architectures such as Vision Transformer (ViT) and ConvNeXt may be explored to further enhance classification performance. The explainability component can also be strengthened by integrating additional XAI techniques such as LIME and SHAP alongside Grad-CAM++. Furthermore, the proposed framework can be enhanced by supporting multimodal diagnosis through the integration of microscopic images with laboratory reports, patient history, and genetic information. Future versions may also include automated PDF-based diagnostic report generation, personalized clinical recommendations, and validation on large-scale clinical datasets to facilitate deployment in real-world healthcare environments.

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