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A Hybrid Explainable Learning System for Automated Bone Cancer Diagnosis Using Medical Imaging

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ABSTRACT:

The diagnosis of a bone tumor from medical images is a challenging task due to the tumor's nature complexity and the image's interpretation complexity. Although deep learning-based approaches can effectively diagnose a tumor automatically, the available methods have limited contribution to the overall understanding of the diagnosis. This work proposed an hybrid explainable machine learning approach for the automated diagnosis of bone cancer from medical images. The paper discussed the possibility of using the deep learning-based features extracting with handcrafted texture features for the tumor classification task. Together with transfer learning, data augmentation, and hyperparameter optimization, Grad-CAM was applied for better interpretation of the model. The work proposed to implement a web application for medical image uploading for automatic diagnosis. The study aimed to contribute to the field by providing higher accuracy and explainability for diagnosis, thus improving detection and treatment of cancer.

Keywords: Bone Cancer; Medical Imaging; Deep Learning; Hybrid
Feature Extraction; Transfer Learning; Grad-CAM; Explainable Artificial Intelligence; Computer-Aided Diagnosis

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I. INTRODUCTION

Bone cancer is a severe musculoskeletal disease that emerges when healthy cells turn into cancerous cells and uncontrollable tumors grow. The primary bone cancer occurs in normal cells in legs, thigh, and pelvis, leading to osteosarcomas, chondrosarcomas, and Ewing's sarcomas (World Health Organization, 2021). Early detection of this disease decreases the mortality rate and allows clinicians to understand what therapy is better for the patient. It can be challenging to differentiate between benign and malignant tumors because of the similarities of x-ray images and the complexity of the structure of bones. X-ray examinations, computerized tomography scans, and magnetic resonance imaging scans are the standard methods of diagnosis and observing the progress of the tumor. An xray is the most affordable and straightforward procedure that can highlight the presence of cancer, nevertheless, it requires professionals with a lot of experience to read the results (Liu et al., 2021). Moreover, with x-ray, it is difficult to define the stage of malignancy and the exact location of a tumor. The new approach to analyzing the results of x-ray examinations is building a computerbased automatic detection system using convolutional neural networks and deep learning concepts to identify cancerous tumors (Liu et al., 2021). The current study will address the role of convolutional neural networks in medical image recognition, explain how transfer learning resolves the issue of insufficient data, and develop a hybrid deep learning computer-aided diagnosis system for classifying bone cancer. Furthermore, the article will discuss how to apply gradient-weighted class activation mapping for explaining predictions in diagnosing cancer and design a web-based user interface for uploading x-ray images of the bone and receiving reports about cancer diagnosis.

The current study will concentrate on the development of computer aided-diagnosis systems for classifying and diagnosing bone cancer accurately. Previous research reported achieving a high classification accuracy, however, they did not address the problem of providing an adequate interpretation of the results (Liu et al., 2021). Furthermore, most of the researchers used to use only deep learning features for cancer diagnosis, ignoring other image recognition features like handcrafted texture analysis (Liu et al., 2021). In addition, the articles lacked graphical user interfaces (GUIs) for displaying diagnostic results, making their results difficult to implement in practice. Thus, the current research will utilize the features of hybrid machine learning algorithms, which demonstrated the best performance in experiments, and introduce an approach to explain the predicted cancer diagnosis using Grad-CAM.

II. RELATED WORK

Deep Learning Driven Radiographic Classification of Primary Bone Tumors using Attention Augmented Hybrid Models (2026) The authors suggested an attention-augmented hybrid deep learning framework for classifying primary bone tumors from radiographic X-ray images. The proposed method used BTXRD dataset and image preprocessing, attention mechanisms, and deep convolutional networks to achieve accurate classification with enhanced features. The results showed that the proposed framework attains high classification accuracy and better feature representation than conventional convolutional networks. However, the method depends mainly on deep features and lacks handcrafted texture descriptors and an explainable clinical decision-support interface.

Deep Learning in Medical Image Analysis for Bone Tumor: A Comprehensive Survey (2026)

The authors performed a comprehensive survey of the latest deep learning methods for analyzing medical images in bone tumor detection and classification tasks. The study highlighted the convolutional network architectures, transfer learning strategies, and explainable AI approaches used in bone tumor classification and detection. The authors also identified research directions and challenges in developing robust and explainable deep learning systems for medical image analysis of bone tumors. The findings revealed the limitations of existing convolutional networks and the need for more reliable and explainable models for clinical applications.

Multimodal Deep Learning for Bone Tumor Diagnosis wit Clinical Imaging, Pathology and Blood Biomarkers (2025) The authors suggested a multimodal deep learning framework that uses clinical images, pathology, and blood biomarkers for bone tumor diagnosis. The study demonstrated the effectiveness of the multimodal learning strategy in improving diagnostic accuracy and clinical decision-support for bone tumor analysis. The results showed that the proposed method achieved reliable results by combining different clinical data types. However, the method's reliance on multiple data types limits its application in medical settings that require automated analysis of medical X-ray images only. 4. Enhancing Transparency in Medical Imaging: DenseNet121 Based Transfer Learning Approach for Bone Cancer Detection (2025)

The authors proposed a transfer learning approach based on DenseNet121 architecture for automated detection of bone cancer from medical images. The study used Grad-CAM to visualize image features and enhance the transparency of the deep learning model for clinical applications. The results showed that the proposed method attains desirable diagnostic performance with improved visualization to support clinical decisions. However, the study focused mainly on transfer learning approaches and did not explore hybridization of different features for better performance.

Domain Adaptive Bone Tumor Detection Framework (2025) The authors suggested a domain adaptation framework for improving the performance of bone tumor detection models across different medical institutions. The study demonstrated how domain adaptation techniques can enhance the generalization performance of deep learning models in tumor detection tasks. The results showed that the proposed method attained desirable performance in adapting to different institutional data distributions. However, the study focused mainly on detection tasks and did not address the need for explainability and hybrid features for tumor classification.

Enhancing Bone Tumor Diagnosis using Deep CNNs, Tumor Severity Classification and LLaMA-Driven Textual Explanations (2025)

The authors proposed a deep learning framework that uses convolutional networks to classify bone tumors and generate textual explanations for clinical support. The method addressed the need for explainable AI in bone tumor diagnosis by integrating CNNs with LLaMA-driven textual explanations and tumor severity classification. The study showed that the proposed method enhanced the interpretability of deep learning features for better clinical decisions. However, the complexity of the model increases due to the use of large language models for textual explanations.

Ref.	Approach	Accuracy / Performance	Limitation
[1]	Attention-Augmented Hybrid CNN with BTXRD Dataset	Achieved high classification accuracy and outperformed conventional CNN models in bone tumor classification.	Relies primarily on deep learning features without integrating handcrafted texture features or explainable deployment mechanisms.
[2]	Comprehensive Survey of Deep Learning Methods for Bone Tumor Analysis	Reviewed recent advances in CNNs, transfer learning, Vision Transformers, and Explainable AI (XAI) for bone tumor diagnosis.	Survey paper that provides comprehensive analysis but does not propose or validate a practical diagnostic framework.
[3]	Multimodal Deep Learning using Clinical Images, Pathology, and Blood Biomarkers	Improved diagnostic performance by integrating multiple clinical data modalities for comprehensive bone tumor diagnosis.	Requires multimodal clinical data and substantial computational resources, limiting practical implementation in X-ray-only systems.
[4]	DenseNet121-Based Transfer Learning with Grad-CAM	Demonstrated high bone cancer classification performance while improving model interpretability through Grad-CAM visualization.	Focuses exclusively on deep learning features without incorporating handcrafted texture feature extraction.
[5]	Domain Adaptive Bone Tumor Detection Framework	Improved model generalization across different imaging domains while maintaining reliable detection performance.	Primarily designed for tumor detection rather than explainable bone tumor classification.
[6]	Deep CNN with Tumor Severity Classification and LLaMA-Based Explanations	Achieved accurate tumor classification with severity assessment and AI-generated textual explanations.	Increased computational complexity and deployment overhead due to the integration of large language models.

III. METHODOLOGY

The proposed hybrid explainable machine learning approach to automate the diagnosis of bone cancer from X-ray medical images is articulated with a series of steps including data acquisition, image preprocessing, feature extraction, fusion, classification, and web-based decision support. This methodology enables an efficient way of analyzing the data using deep learning and handcrafted features with an aim of attaining higher accuracy and robustness in detecting bone cancer, thereby facilitating interpretation of the results through the explainable AI model. Fig 1 below shows the proposed methodology workflow.

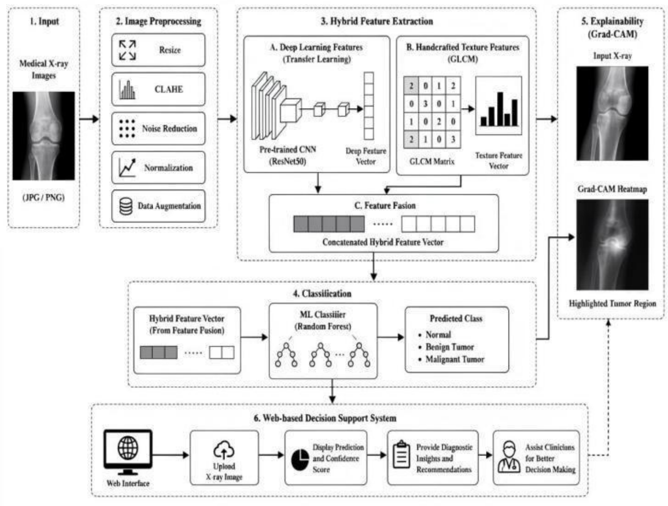

Fig. 1. Proposed hybrid explainable machine learning framework for automated bone cancer diagnosis using medical imaging.

A. Data Acquisition

The first step was to acquire the bone X-ray image dataset for the task at hand. This was done by downloading the images from the public repository as the target images. The downloaded images were categorized into diseased and normal bone images and partitioned into training, testing, and validation sets for training the automated model in classifying the images. Fig 2 below shows the samples from the BTXRD X-Ray dataset

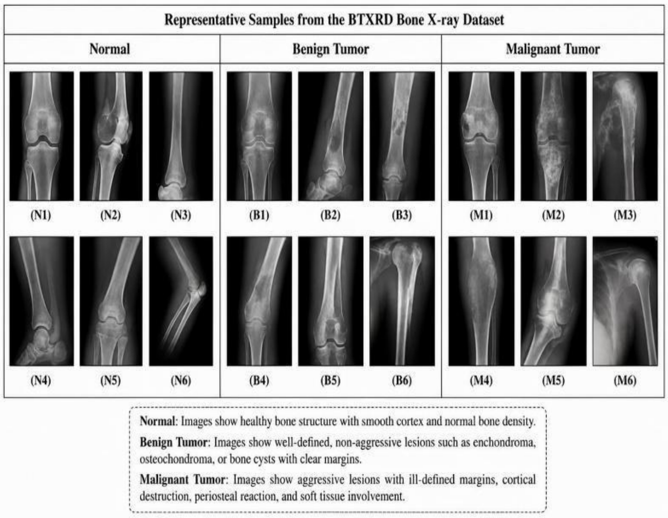

Fig. 2. Representative samples from the BTXRD bone X-ray dataset.

B. Image Preprocessing

This is the second stage of the proposed approach, which involves standardizing the input image size, enhancing image contrast, and executing other processes required to train the deep learning model using the input images. The data augmentation procedures such as rotation, flipping, and zooming were applied to increase the number of training samples and reduce the chances of overfitting. Fig 3 below shows the Image Processing pipeline.

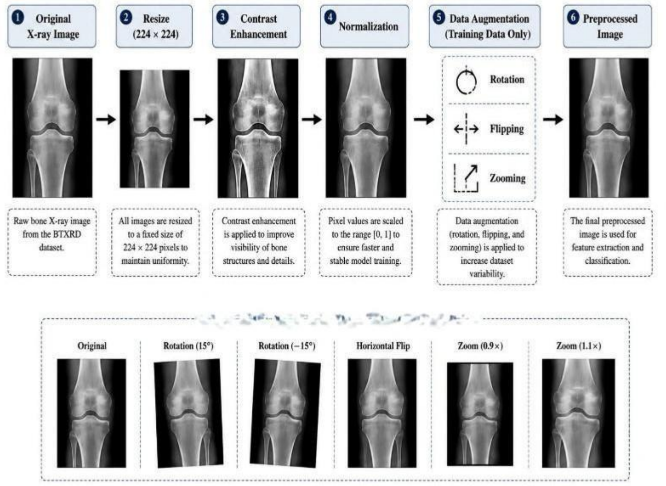

Fig. 3. Image preprocessing pipeline used in the proposed framework.

C. Hybrid Feature Extraction

The hybrid feature extraction step involved using features from the pretrained convolutional network using transfer learning and manually extracted texture features using the grey level co-occurrence matrix (GLCM). The transfer learning process helped extract high-level features from the images. The next step was to fuse these deep features with handcrafted features in order to boost the model performance in classifying the two classes of images. Fig 4 below shows the Hybrid Feature Extraction.

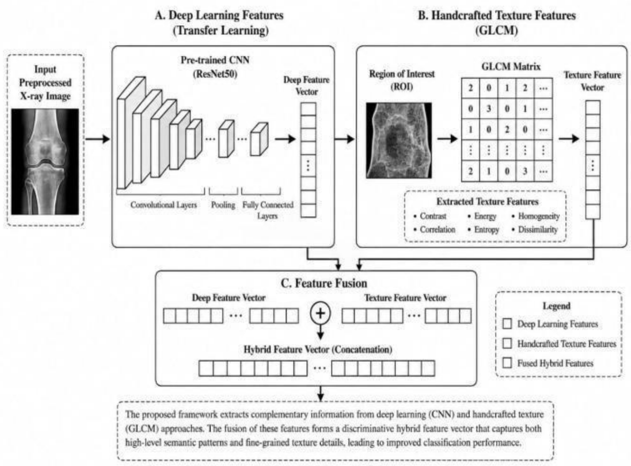

Fig. 4. Hybrid feature extraction using deep learning features and GLCM texture features with feature fusion.

D. Bone Tumor Classification

The fused features were then inputted into the classification algorithm to determine the input image class, with transfer learning and hyperparameter optimization applied to fine-tune the performance of the classifier. This approach was expected to yield a reliable and efficient classification model based on the fused features in distinguishing between normal and diseased bone images.

E. Explainable AI

The third step was to generate a heatmap visualization of the classified image using gradient-weighted class activation mapping (Grad-CAM). This helped in visualizing the image regions highlighted by the classifier in making the prediction decisions. The heatmaps were used to explain how the model arrived at its conclusions and to build the trust of clinicians in this approach. Fig 5 below shows the Grad-CAM visualization for Model Explainability.

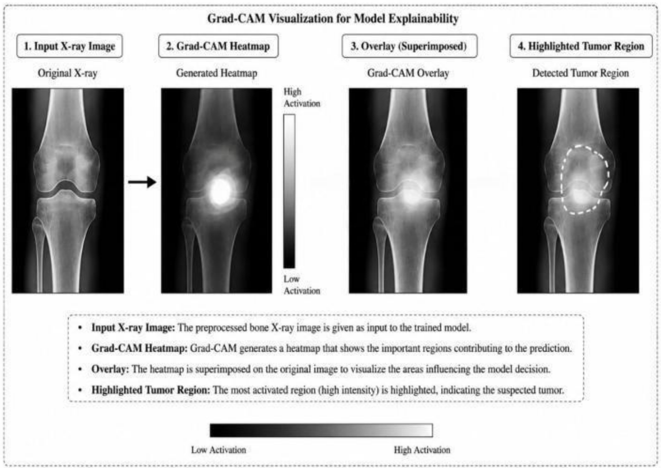

Fig. 5. Grad-CAM visualization for explainable bone tumor prediction.

F. Web-Based Decision Support

Finally, the proposed approach was deployed as a web application where users could upload medical images for screening and automated diagnosis and receive the results in the form of predicted labels and Grad-CAM visualizations.

IV. RESULTS AND DISCUSSION

The proposed hybrid explainable machine learning framework aims to provide an improved automated diagnosis of bone cancer from medical images by combining deep learning-based feature extraction process and handcrafted texture analysis for effective prediction. Contrary to the use of only convolutional neural networks in existing methods, the proposed framework considers multiple features for improved identification of normal and malignant bone tissues.

The proposed image preprocessing steps including image resizing, normalization, contrast enhancement, and data augmentation are anticipated to yield a better representation of X-ray images of the bone. As a result, an improved set of features will be extracted by the classifier, enabling reduced overfitting and enhanced learning process during diagnosis. On the other hand, the proposed hybrid approach to feature extraction based on the combination of deep learning and handcrafted texture analysis is expected to yield superior features useful for effective prediction. While deep learning methods based on transfer learning enables the extraction of high-order features about the image, handcrafted texture analysis helps extract additional texture features related to the characteristics of the bone. Thus, the combination of both methods is anticipated to generate hybrid features valuable for improved diagnostic results.

The proposed method based on transfer learning is expected to yield better results by reducing training time since the diagnostic model does not require training from the scratch. Instead, it utilizes the pretrained deep learning framework to extract features about normal and malignant bone tissues, which improves the learning process and reduces training time. In addition, hyperparameter tuning is necessary to optimize the training process by choosing the best algorithm, learning rate, batch size, number of epochs, and optimizer.

Besides combining deep learning and handcrafted texture analysis, the proposed framework also incorporates explainable artificial intelligence based on Grad-CAM to highlight image features important to the diagnostic model. The explainable AI is anticipated to yield heatmaps indicating the image regions the diagnostic model uses to make predictions. As a result, medical professionals can utilize the heatmap to understand how the diagnostic model arrived at its predictions and confirmed whether it highlights the relevant region for cancer diagnosis. Overall, the use of explainable artificial intelligence increases the model's trustworthiness, reliability, and transparency.

Finally, the proposed web-based support system aims to provide an effective automated diagnostic framework for identifying malignant bone cancer. Medical professionals or users can upload the image, and the web application can automatically perform preprocessing, feature extraction, classification, and heatmap generation while displaying the final diagnostic result. Thus, the web-based approach enables the use of the application by medical workers for faster diagnosis for screening purposes. Ultimately, the proposed automated diagnostic framework for detecting malignant bone cancer is anticipated to address the limitations of existing methods identified in the literature review section. Although the reviewed articles have considered various approaches for improving deep learning-based diagnostic models, they failed to consider various alternative features for analyzing medical images. Moreover, most existing approaches utilize only deep learning features for diagnosis, lack visual explanation about the model's prediction process, and require additional clinical records for diagnosis. On the contrary, the proposed approach incorporates hybrid features from both handcrafted texture analysis and deep learning while implementing a web-based support system to facilitate faster diagnosis and screening of bone cancer. In addition, the framework includes an explainable artificial intelligence module to make the diagnostic process transparent for medical workers and ensure reliability of deep learning-based diagnosis. Therefore, the proposed framework addresses the limitations of existing methods to enhance screening and early prediction of cancer.

V. FUTURE ENHANCEMENT

The suggested hybrid explainable machine learning framework can be enhanced by using a broader range of medical image data from various healthcare institutions to improve diagnostic accuracy. In addition, future research should be done to ensure that other imaging technologies, for example, computerized tomography (CT) and magnetic resonance imaging (MRI), can be utilized to identify different forms of bone cancer.

The performance of the developed classification framework can be improved by leveraging the recent advances in deep learning algorithms, for example, Vision Transformers or hybrid CNN-based networks and models. At the same time, the explainability of the suggested approach can be enhanced by combining various XAI methods, for example, Local Interpretable Model-agnostic Explanations (LIME) and Shapley Additive explanations (SHAP).

The suggested web-based decision support system can be improved by utilizing cloud platforms for storing patients' data and generating reports automatically to make the system more competitive.

VI. CONCLUSION

This paper proposed an explainable hybrid machine learning model for automated diagnosis of bone cancer using medical x-ray images. Our framework is based on the combination of an end-to-end deep learning model with traditional texture-based features to highlight the relevant information for diagnosis. To increase the performance and applicability of our approach, we applied transfer learning, data augmentation, and hyperparameter optimization. Finally, we integrated Grad-CAM explanation algorithm to increase the model's transparency and trustworthiness.

In turn, we expect that our open-source web application for diagnosis of bone cancer utilizing a machine learning model would be beneficial for clinicians because it allows for fast screening of patients with possible cancer. We believe that our method could be helpful in clinical practice to support the doctors in making decisions about the patient's treatment. We also expect that the proposed solution could fill the gap between the high accuracy of image recognition models and the necessity for explainable and thus trustworthy computer-aided diagnosis systems. Therefore, our research aims to contribute to the ongoing development of artificial intelligence systems that support clinicians in diagnosing cancer and treating the disease in patients.

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REFERENCES

[1] S. M. Bokhari and M. Shafi, "Deep Learning Driven Radiographic Classification of Primary Bone Tumors Using Attention Augmented Hybrid Models," Biomedical Signal Processing and Control , vol. 113, p. 108888, 2026.

[2] Deep Learning in Medical Image Analysis for Bone Tumor: A Comprehensive Survey, 2026.

[3] Multimodal Deep Learning for Bone Tumor Diagnosis with Clinical Imaging, Pathology and Blood Biomarkers, Elsevier, 2025.

[4] Enhancing Transparency in Medical Imaging: A DenseNet121 Based Transfer Learning Approach for Bone Cancer Detection from Radiographs, 2025.

[5] Domain Adaptive Bone Tumor Detection Framework, 2025.

[6] Enhancing Bone Tumor Diagnosis Using Deep CNNs, Tumor Severity Classification and LLaMA-Driven Textual Explanations, 2025.

[7] S.-Y. Rhyou et al., "Tracking Temporal Progression of Benign Bone Tumors Through X-ray Based Detection and Segmentation," Scientific Reports , vol. 15, 2025.

[8] A. Ajay, R. Karthik, A. S. Bisht, and P. Uppuluri, "BoneVisionNet: A Deep Learning Approach for the Classification of Bone Tumours from Radiographs Using a Triple Fusion Attention Network of Transformer and CNNs with XAI Visualizations," Computerized Medical Imaging and Graphics , 2025.

[9] A. Tamizifar, S. Berenjkoub, Z. SobhaniNia, N. Karimi, P. Khadivi, and S. Samavi, "Preprocessing and Postprocessing for Robust Bone Tumor Detection: A Siamese-Guided Weighted Augmentation Pipeline," in 2025 IEEE World AI IoT Congress (AIIoT) , Seattle, WA, USA, 2025, pp. 450-455.

[10] R. Ramamoorthy, "Deep-BNet: A Novel Architecture of DeepBone Network Layer Based Bone Cancer Detection and Classification," International Journal of Applied Mathematics , vol. 38, no. 7S, pp. 790-802, 2025.

[11] S. Chen, Y. Peng, Y. Liu, P. Wang, and T. Liu, "Enhancing YOLOv11 with Large Kernel Attention and Multi-scale Fusion for Accurate Small and Multi-lesion Bone Tumor Detection in Radiographs," Diagnostics , vol. 15, no. 16, p. 1988, 2025.

[12] Shunhan Yao et al., "BTXRD: Bone Tumor X-ray Radiograph Dataset for Detection and Segmentation," 2024.Using Image Processing: A Comprehensive Review": A Comprehensive Review", Malaysian J. Sci. Adv. Tech., vol. 2, no. 4, pp. 174–182, Oct. 2022. .

