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AI-BASED DIAGNOSTIC TOOL FOR DETECTION OF OSTEOPOROSIS USING CLINICAL DATA AND MEDICAL IMAGING

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Abstract: Osteoporosis is a progressive bone disorder that reduces bone density and deteriorates bone structure, significantly increasing fracture risk. Traditional diagnostic tools like DEXA scans are often expensive and inaccessible, particularly in rural or under-resourced regions. This project introduces an AI-based diagnostic system designed to detect osteoporosis using X-ray images and clinical data.

The system features three main modules: a CNN model trained to classify spine and knee X-rays, a machine learning-based clinical predictor using patient data, and a stage detection module for assessing disease severity. The CNN model achieved approximately 95% accuracy, while the clinical predictor using Gradient Boosting reached 92.01%.

A Flask-based web application provides an easy-to-use interface for patients and healthcare professionals. The system also delivers personalized treatment recommendations and optional doctor consultation links. By combining image analysis and clinical data evaluation, this hybrid approach offers a cost-effective, accessible, and accurate tool for early osteoporosis detection, especially beneficial in underserved areas.

I. INTRODUCTION

Osteoporosis is a progressive bone disease characterized by decreased bone mass and structural deterioration of bone tissue, resulting in an increased risk of fractures. It is especially prevalent among older adults and postmenopausal women and represents a significant public health concern worldwide. According to the International Osteoporosis Foundation (IOF), osteoporosis affects more than 200 million people globally and causes Over 8.9 million fractures annually. Early diagnosis and appropriate treatment can substantially reduce the risk of severe complications and improve patient quality of life. Dual-energy X-ray absorptiometry (DEXA) is the current gold standard for measuring bone mineral density (BMD) and diagnosing osteoporosis. However, DEXA scans are expensive, require specialized equipment, and are not readily accessible in many rural or resource-limited areas. These limitations make population-wide screening and early diagnosis challenging.

In recent years, Artificial Intelligence (AI) and Machine Learning (ML) have emerged as transformative tools in healthcare, particularly in medical imaging and diagnostics. Deep Learning, a subset of ML, has demonstrated exceptional performance in tasks like image classification, object detection, and medical anomaly recognition. Specifically, Convolutional Neural Networks (CNNs) have shown promising results in analyzing radiographic images to detect signs of osteoporosis.

By integrating CNN-based image analysis with clinical data, it becomes possible to build a robust and cost-effective diagnostic system for osteoporosis that does not solely rely on DEXA scans. This multimodal approach can enhance prediction accuracy and make osteoporosis screening more accessible to underserved population.

II. METHODOLOGY

Fig1. shows the block diagram of osteoporosis diagnostic system. The below contains overview of methodology.

1. Data Collection:

- Collected annotated spine and knee X-ray images from medical repositories and hospital archives.
- Gathered clinical data including age, gender, lifestyle habits, diet, and medical history.
- Ensured dataset diversity across all age groups and osteoporosis severity levels.

2. Pre-processing:

- Converted X-rays to gray-scale, resized to 224×224 pixels, and normalized pixel values.
- Enhanced contrast using CLAHE and applied augmentation (rotation, flipping, zooming).

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- Cleaned clinical data, handled missing values, and encoded categorical variables.

3. **CNN Model Development:**
- Built a custom CNN model to classify X-ray images into Normal, Spine Osteoporosis, and Knee Osteoporosis.
- Fine-tuned hyper-parameters for better generalization and performance.
- Achieved ~95% classification accuracy on test data.

4. **Knee Stage Detection:**
- Ensured balanced class distribution during training for better stage-wise accuracy.
- Developed a separate CNN to classify knee X-rays into five stages: Normal to Most Severe.
- Triggered treatment recommendations for abnormal cases.

5. **Clinical Data Prediction:**
- Trained multiple machine learning models (e.g., Gradient Boosting, SVM, Random Forest) on patient data.
- Used cross-validation and selected the highest-performing model (~92.01% accuracy).
- Predicted osteoporosis risk based on structured clinical inputs.

6. **Validation & Evaluation:**
- Split data into training, validation, and testing sets (70:20:10 ratio).
- Evaluated model performance using accuracy, confusion matrix, and ROC curves.
- Applied regularization techniques like dropout and batch normalization.

7. **Recommendation System:**
- Activated when a non-normal prediction is detected.
- Suggested stage-specific medication, exercises, and dietary plans.
- Linked results to treatment web pages with detailed guidance.

8. **User Interface:**
- Developed a Flask-based web interface with modules for image and clinical data prediction.
- Integrated features like login system, result display, and treatment suggestion buttons.
- Provided "Consult Doctor" redirection to platforms like Ask- Apollo.

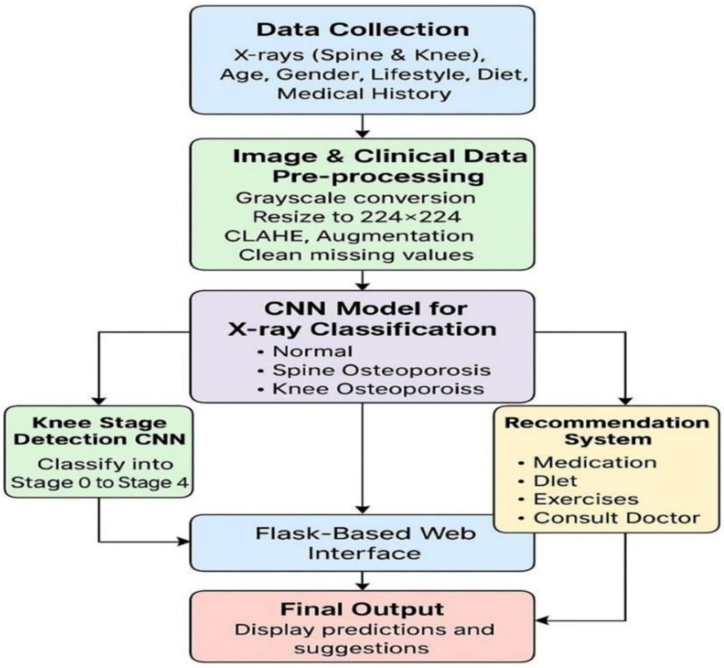

Fig1. Block diagram of Osteoporosis diagnostic system

III. OBJECTIVES

The primary objective of this project is to develop an AI-driven diagnostic system for osteoporosis detection using medical imaging and clinical data. The specific goals are:

1. **X-ray Image Classification:** Build a deep learning model using Convolutional Neural Networks (CNNs) to analyze spine and knee X-ray images and classify them into categories such as Normal, Spine Osteoporosis, or Knee Osteoporosis.

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2. **Clinical Risk Prediction:** Design a machine learning module that assesses the likelihood of osteoporosis based on patient-specific clinical data like age, gender, lifestyle, hormonal conditions, and medical history.
3. **Stage Detection of Knee Osteoporosis**: Implement a stage-wise classification system to detect the severity of knee osteoporosis (Healthy, Mild, Moderate, Severe, Most Severe) from X-ray images.
4. **Web-based Deployment with Consultation Support:** Develop a Flask- based web interface that offers secure login, easy access to all diagnostic modules, and connects users to medical specialists for further consultation. The system is designed to be cost-effective and accessible, especially in rural and resource-limited healthcare environments.

HARDWARE REQUIREMENT

1. **Processor**: Intel Core i5 or higher — a reliable processor that supports smooth execution of AI models and web services.
2. **RAM: Minimum 8 GB —** sufficient for model loading, training, and concurrent user interactions.
3. **Storage:** At least 80 GB — ensures space for datasets, model weights, and application files.
4. **GPU (Optional):** NVIDIA GTX 1050 or better — accelerates model training and inference time for deep learning tasks.

SOFTWARE REQUIREMENT

1. **Operating System:** Windows 11 (64-bit) — stable environment for Python development and web hosting.
2. **Python Version:** 3.8 or above — compatible with modern AI/ML libraries and Flask framework.

Libraries:

- **TensorFlow & Keras –** for building and training deep learning models.
- **Flask –** to develop the web-based user interface.
- **Pandas, Scikit-learn –** for clinical data processing and machine learning.
- **OpenCV –** used for X-ray image handling and preprocessing operations like CLAHE.

IV. RESULTS AND DISCUSSION

The system was designed as a multi-module diagnostic tool combining image-based deep learning and clinical data-based machine learning.
The core work can be categorized into the following components:

1. **Image-Based Osteoporosis Prediction**: A custom Convolutional Neural Network (CNN) was developed to classify uploaded X-ray images into three categories: Normal, Spine Osteoporosis, and Knee Osteoporosis. The model was trained on preprocessed gray-scale images with augmentation techniques to enhance generalization. Fig2 and Fig3 show how prediction result system works.
2. **Clinical Data-Based Prediction:** A separate module was built using machine learning algorithms to predict osteoporosis based on clinical parameters such as age, gender, family history, calcium intake, physical activity, and other risk factors. Multiple classifiers were compared, and the best-performing model was selected for integration.
3. **Knee Stage Detection:** An additional CNN model was implemented to detect the stage of knee osteoporosis, classifying images into: Normal, Mild, Moderate, Severe and Most Severe. This allowed for detailed severity-based recommendations.
4. **Web Application Deployment:** A Flask- based web interface was developed to unify all the models, allowing users to register, log in, upload X-rays or clinical data, and receive both diagnosis and treatment suggestions in real-time.

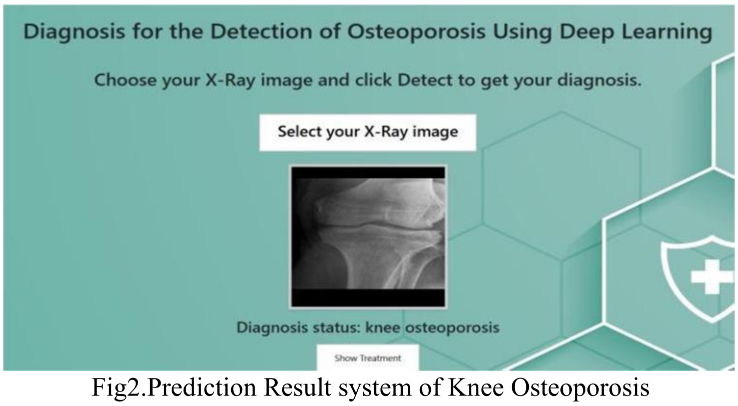

Fig2.Prediction Result system of Knee Osteoporosis

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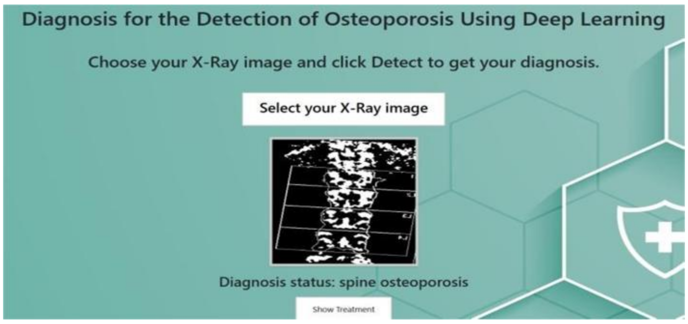

Fig3.Prediction Result system of Spine Osteoporosis

V. ADVANTAGES

The proposed AI-based diagnostic tool offers several benefits over traditional osteoporosis detection methods:

- **Cost-Effective Diagnosis:** By using standard X-ray images and clinical data, the system eliminates the dependency on expensive DEXA scans, making it affordable for wide- scale screening.
- **High Accuracy:** The CNN-based image classification model achieved approximately 95% accuracy, while the clinical prediction model reached 92.01%, ensuring reliable diagnostic performance.
- **Dual-Modality Detection:** The combination of image-based and data-driven analysis enhances overall diagnostic accuracy and reduces false positives and false negatives.
- **Early Stage Detection:** The inclusion of knee stage classification helps in identifying the severity of osteoporosis early, enabling timely medical intervention.
- **User-Friendly Interface**: A web-based platform ensures easy access for both healthcare professionals and patients, with minimal training requirements.
- **Real-Time Results:** The tool delivers near- instant predictions, supporting fast clinical decision-making in time-sensitive environments.
- **Accessible in Low-Resource Settings:** The lightweight system architecture allows deployment in rural and underserved areas where advanced diagnostic tools are unavailable.
- **Personalized Recommendations:** The system provides individualized treatment suggestions, including diet, exercise, and medication, enhancing patient care and follow-up.

VI. CONCLUSION AND FUTURE SCOPE

The project titled “AI-Based Diagnostic Tool for Detection of Osteoporosis Using Clinical Data and Medical Imaging” aimed to provide an accessible, automated, and accurate solution for early osteoporosis detection. This work successfully integrates two critical diagnostic approaches: deep learning-based image analysis and machine learning-based clinical data prediction.

By combining these two domains, the system improves the overall diagnostic accuracy and offers a user-friendly interface to support real-time decision- making. The deep learning model was trained using a Convolutional Neural Network (CNN) to classify X- ray images of the spine and knee into categories such as Normal, Spine Osteoporosis, and Knee Osteoporosis. Simultaneously, multiple machine learning algorithms were applied to clinical features such as age, gender, calcium intake, physical activity, and medical history to assess osteoporosis risk. The system intelligently selects the most accurate model to make the final prediction.

In addition to diagnosis, the tool also includes a treatment recommendation module that suggests exercises, dietary guidelines, and medication based on the user’s condition. Further-more, it provides the option to consult a doctor via integrated external platforms like Apollo, enhancing the practicality and usability of the system in real-world healthcare scenarios.

Key Conclusions Drawn

- The integration of CNNs for image analysis and ML models for clinical data resulted in a highly accurate and reliable diagnostic system.
- The system is capable of detecting not only the presence of osteoporosis but also classifying its type and severity, specifically in knee cases.

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- The use of standard X-ray images instead of expensive DEXA scans makes the tool more accessible and affordable.
- The web-based deployment using Flask ensures ease of use and allows doctors to interact with the system from any location.
- Treatment suggestions and doctor consultation links add value to the diagnosis and make the system more holistic.

Scope for Future Work:
While the current system achieves its goals effectively, there is still scope for further enhancement:
- **Integration of real-time image** capture from mobile or camera-based devices to allow instant scanning without prior upload.
- **Expansion of dataset** across diverse demographics to improve model generalization and robustness.
- **Addition of BMD values** or integration with DEXA scan outputs (if available) to further validate diagnosis.
- **Mobile application development** to make the solution more accessible in remote or rural areas.
- **Real-time alerts or patient tracking** system to monitor progress and suggest timely follow-ups or lifestyle changes.

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