Medical Image Analysis using Artificial Intelligence: Current Status and Future Directions

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Background

Medical imaging plays a crucial role in diagnosis, treatment, and monitoring of various health conditions. With the rapid advancements in artificial intelligence (AI), medical image analysis has undergone a transformative evolution. This poster explores the current state and exciting future prospects of utilising AI in medical image analysis.

Brief Overview

Medical imaging is a fundamental diagnostic tool that allows healthcare professionals to visualise the internal structures and functions of the human body. It encompasses a wide range of technologies and techniques designed to capture detailed images of organs, tissues, and bones. Medical imaging plays a crucial role in disease detection, treatment planning, and monitoring the progress of medical interventions.

Artificial Intelligence (AI) in the Medical Field

Artificial Intelligence(AI), has found its application in medicine, encompassing a diverse range of techniques and technologies within the healthcare and medical research domain. Its fundamental objective lies in the utilisation of computational algorithms and models to examine intricate medical data, facilitate clinical decision-making, enhance patient outcomes, and propel medical research forward. AI has the potential to revolutionize healthcare by providing personalized, efficient, and accurate solutions to medical challenges.

- AI offers a number of advantages over traditional analytics and clinical decision-making techniques.
- Learning algorithms can become more precise and accurate as they interact with training data
- Allowing humans to gain unprecedented insights into diagnostics, care processes, treatment variability, and patient outcomes.

AI is making an impact in medicine especially in Medical Imaging

- AI can analyze medical images such as X-rays, MRI scans, CT scans, and pathology slides, aiding in the early detection and diagnosis of diseases like cancer, heart conditions, and neurological disorders.

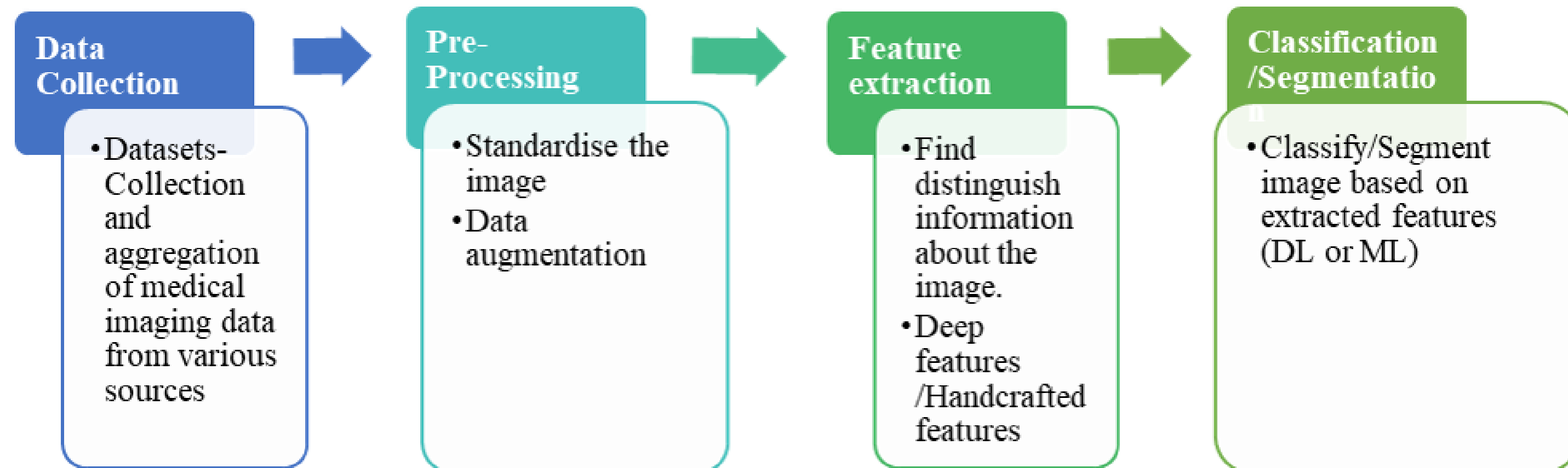Stages involved in the development of an AI-Assisted medical imaging system.

Figure 1. AI-Assisted medical imaging system pipeline

Deep Learning: Convolution Neural Network

A **Convolutional Neural Network (CNN)** is a specialised type of artificial neural network designed for processing and analyzing visual data, such as images and videos.

CNNs are inspired by the human visual system and are highly effective at tasks like image recognition, object detection, and image segmentation.

They have revolutionized computer vision and have been instrumental in various applications, including medical image analysis, self-driving cars, and facial recognition.
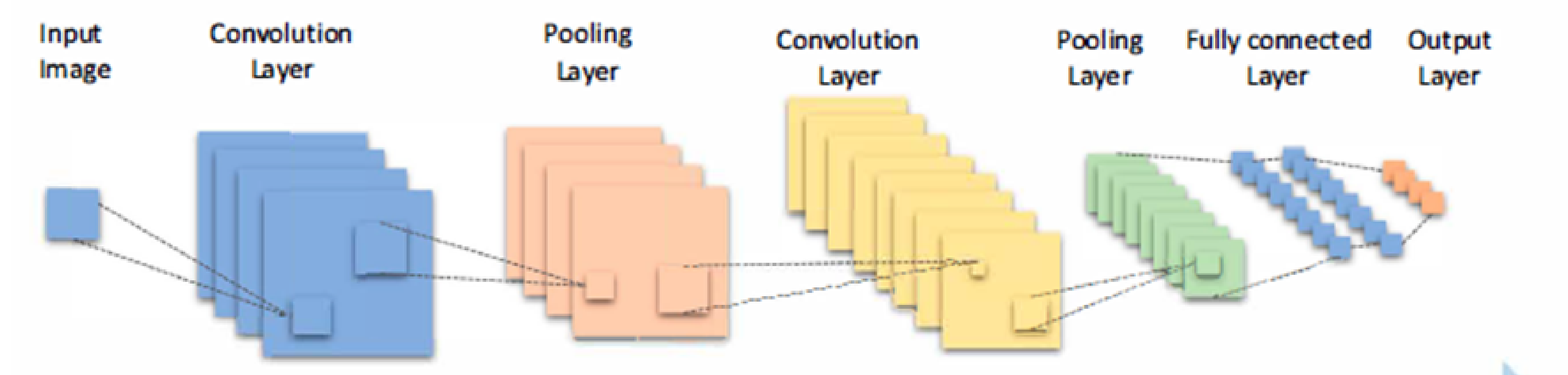

Figure 2. Architecture of CNN

CNN consists of multiple layers, including **convolutional layers** that extract features by convolving filters over the input image to detect patterns, **pooling layers** that downsample the extracted features to reduce dimensionality, and **fully connected layers** that classify the features into different classes.

Use of AI in the detection of medical abnormities

We have achieved favourable testing accuracies during the development of multiple AI-assisted models for detecting medical abnormalities through the implementation of Deep Convolutional Neural Networks (CNNs), including ResNet50 and DenseNet.
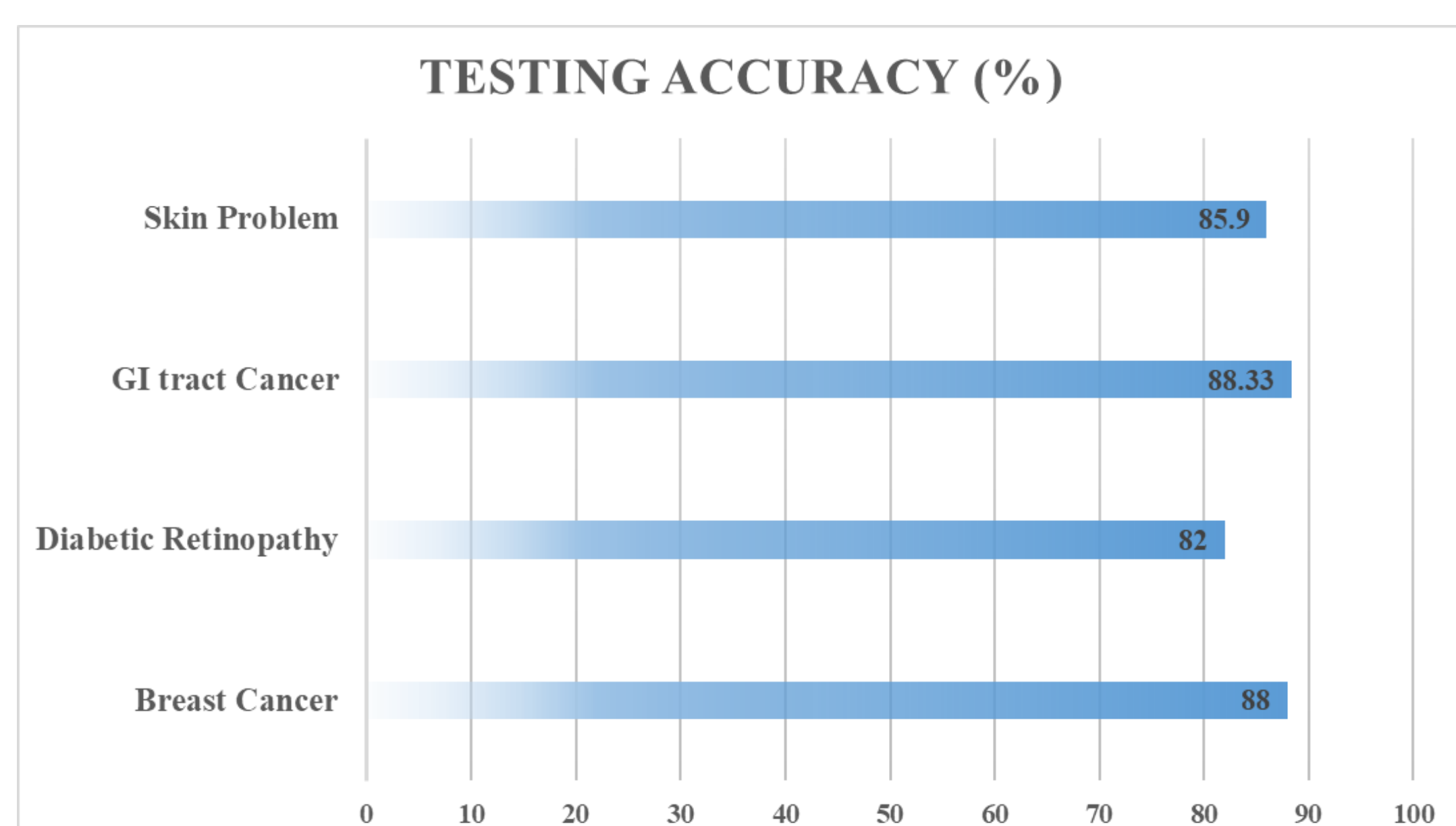

Figure 3. AI-Assisted medical imaging models

Challenges in the development of AI-assisted medical imaging models

AI-assisted medical imaging models have shown great promise in improving the accuracy and efficiency of medical diagnoses. However, the application of such models are often hindered by several challenges such as:

1. **Data Quality and Quantity:** Building effective AI models requires a **large** and **diverse** dataset. In medical imaging, obtaining high-quality labelled data can be challenging due to privacy concerns, the need for expert annotation, and variations in imaging equipment and techniques.
2. **Interpretability:** Many AI models, especially deep learning models, are often considered "**black boxes**" because their decision-making processes are difficult to interpret. In medical settings, it's important for healthcare professionals to understand how the model arrives at its conclusions to build trust and ensure patient safety.

Data Quality and Quantity

- *Data Quality:* The quality of the medical images can be enhanced through the pre-processing pipeline with techniques such **Normalization and Standardization**, **Noise Reduction**, image enhancement through contrast and sharpness.
- *Data Quantity:* Data augmentation has emerged as a good technique to deal with the challenges such as **lack of medical datasets** and **class imbalance**.
  - Data augmentation techniques include:
    - **Basic Image Manipulation**-Generate augmented data by applying transformations such as rotation, scaling, flipping, and cropping.
    - **Generative Adversarial Network (GAN)**-Create synthetic data to augment the dataset with controlled variations. GAN consists of two neural networks, the generator and the discriminator. The generator network learns to create data that is indistinguishable from real data, while the discriminator network learns to differentiate between real and generated data, resulting in the generator producing increasingly realistic data.
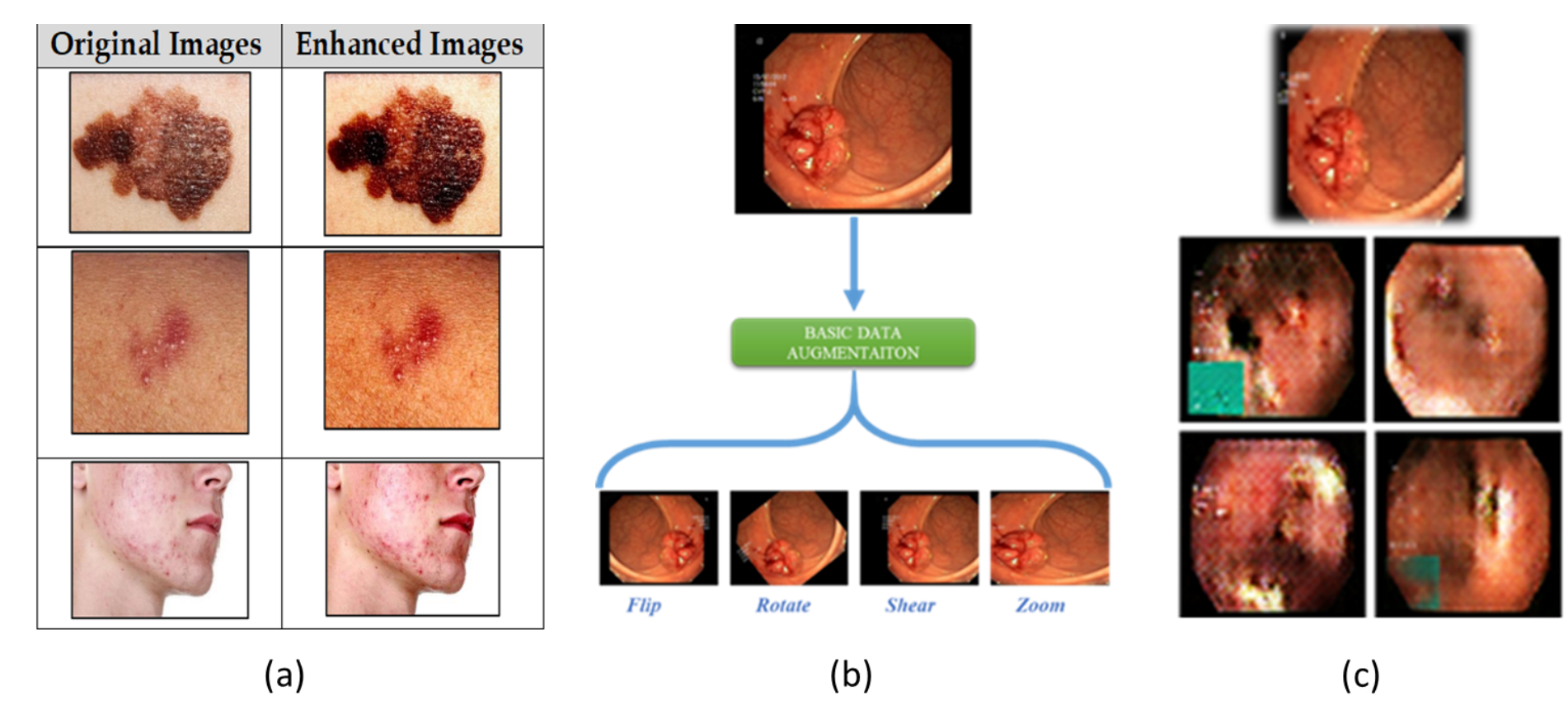

Figure 4. (a): Image Enhancement, (b): Basic image augmentation, (c): GAN augmentation

Interpretability

Despite their effectiveness, there is a **huge hesitancy** among doctors and healthcare institutions in adopting AI-assisted models in clinical practices, primarily due to their perceived nature as computational "black boxes" and **lack of transparency in the decision making processes**.
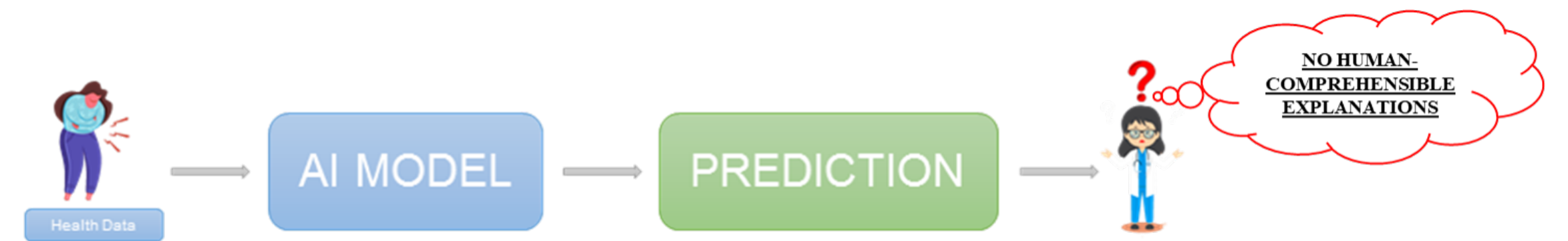
Explainable Artificial Intelligence (XAI) has emerged as a field that offers potential solutions by providing explanations for model predictions. XAI techniques can be categorised into various approaches including attention mechanism and visual explanations These techniques offer insights into the reasoning behind AI-based medical image analysis, facilitating transparency and bridging the gap between AI capabilities and the need for explainability in healthcare applications, thus fostering trust and facilitating the integration of these models into clinical practice.

- **Attention mechanism** allow models to focus on specific parts of input data that are most relevant for making decisions.
- **Visual explanations** involve overlaying informative visualizations on input data to highlight important features or regions that contribute to a model's output. Visual explanation techniques include:
  - **SHAP (SHapley Additive exPlanations)** is a model-agnostic technique derived from cooperative game theory, enabling the interpretation of AI model outputs by quantifying the contributions of individual features to a model's prediction across all possible combinations of features.
  - **Grad-Cam** generates heatmaps that highlight regions in an image by computing gradients of the model's output with respect to the feature maps in the final convolutional layer.
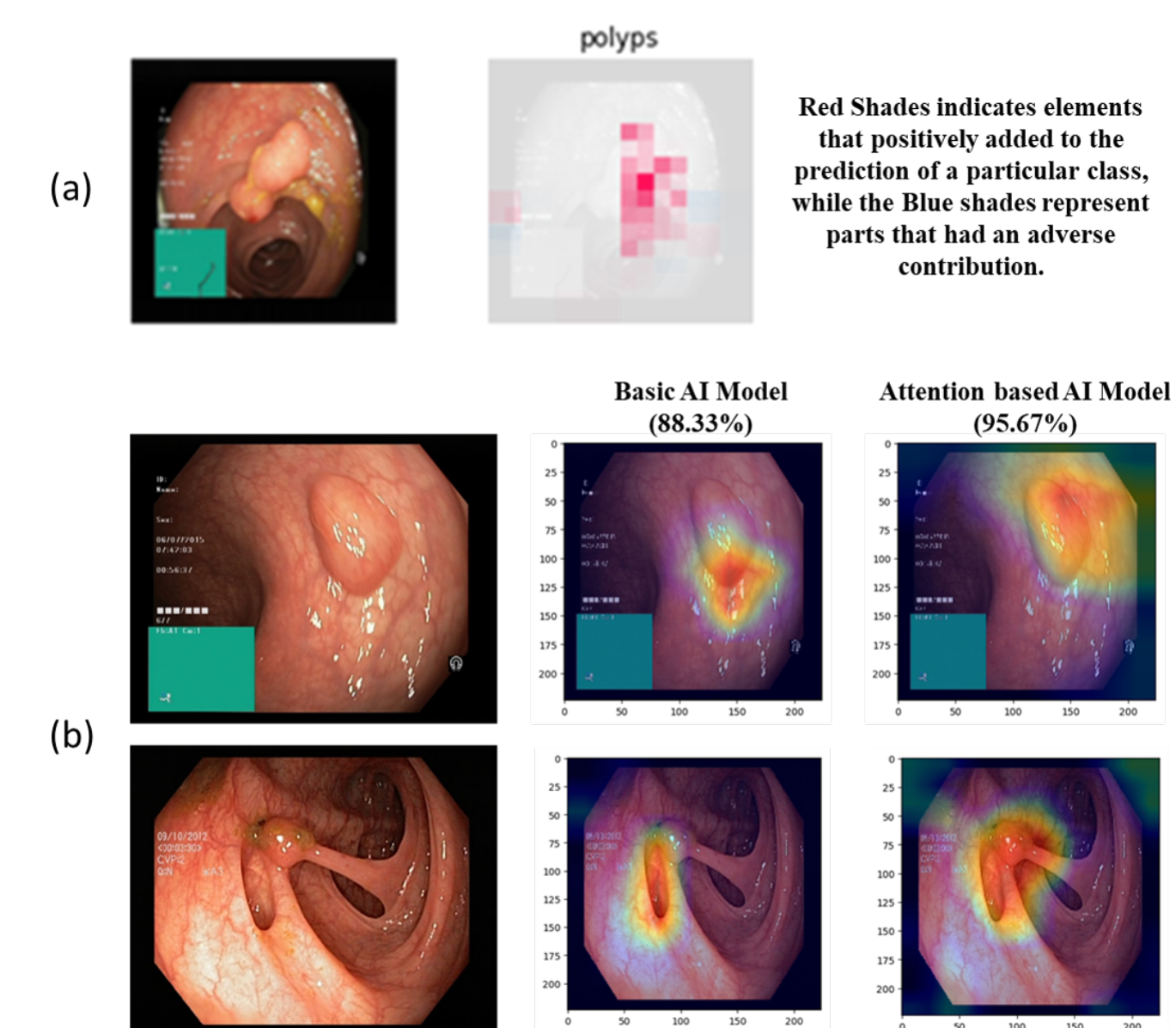

Figure 5. Model visualisation using (a): SHAP, (b):Grad-cam on Basic AI model & Attention based AI model

Future directions

Current AI models have predominantly focused on identifying abnormalities without providing comprehensible explanations for their predictions.

- **Enhanced Diagnostics**- Continue to improve diagnostic accuracy and speed by analyzing medical images for subtle abnormalities that might be missed by human experts. This could lead to earlier and more accurate disease detection.
- **Explainable AI**- Exploration of more XAI techniques that will make AI models more transparent and explainable thus enhancing the trust and acceptance of these technologies among healthcare professionals.