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Wireless Capsule Endoscopy Image Classification: An Explainable AI Approach

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Abstract: This study focuses on improving the accuracy of automated diagnoses in medical imaging, specifically endoscopic images, using advanced deep learning models. We aim to enhance the understanding of these models' decision-making processes by employing Explainable AI (XAI) techniques. Our research uses a subset of the Kvasir-capsule dataset, a Wireless Capsule Endoscopy imaging dataset, concentrating on the top 9 classes for training and testing.MobileNetv3Large is a convolutional neural network (CNN) architecture specifically designed for mobile and edge devices. It is an evolution of the MobileNet architecture, optimized for efficient and lightweight model inference.ResNet152v2 is part of the ResNet (Residual Network) family, known for its deep architecture with residual connections. ResNet152v2 is an extension with 152 layers. These scores surpass previous studies on the same dataset, indicating improved diagnostic reliability. To unravel the decision-making of these models, we utilized XAI techniques, including presenting heat maps that highlight important regions in the images. This effort aims to provide insights into the top-performing deep learning models and demystify their complex decision processes summary, our research not only achieves improved diagnostic reliability but also contributes to the interpretability of deep learning models in the medical imaging domain. The use of Explainable AI techniques allows us to peek into the decision processes of these models, making them more transparent and trustworthy for medical professionals.

Keywords: Wireless Capsule Endoscopy, Explainable AI, Deep Learning, Grad-CAM, SHAP, Gastrointestinal imaging, Interpretability.

INTRODUCTION

The project titled "Wireless Capsule Endoscopy Image Classification: An Explainable AI Approach" focuses on the application of artificial intelligence (AI) in the medical field, specifically in the context of diagnosing gastrointestinal conditions using wireless capsule endoscopy images. Capsule endoscopy is a non-invasive technique that involves patients swallowing a small capsule equipped with a camera, allowing for the visualization of the gastrointestinal tract. In this project, the primary objective is to develop a robust image classification system using AI algorithms to analyze and categorize the captured images. The emphasis on an "Explainable AI Approach" suggests a commitment to transparency and interpretability in the decision-making process of the AI model. This is crucial in a medical setting, where understanding the rationale behind AI predictions is vital for gaining the trust of healthcare professionals and ensuring accurate diagnoses. The project aims to leverage state-of-the-art AI techniques to enhance the efficiency and accuracy of identifying abnormalities or potential diseases within the gastrointestinal system. Additionally, the focus on explain ability ensures that healthcare practitioners can comprehend and validate the model's predictions, facilitating better collaboration between AI systems and medical professionals. Overall, the project holds the potential to revolutionize the diagnostic capabilities in gastroenterology by combining advanced AI technologies with a transparent and interpretable approach, ultimately contributing to more effective and reliable medical decision-maker.

This project aims to develop an advanced system for categorizing images obtained through wireless capsule endoscopy using state-of-the-art deep learning techniques. This involves comprehensive data collection, preprocessing, and feature extraction to enhance image quality and highlight relevant patterns. The implementation will focus on creating an interpretable classification model, leveraging Explainable AI techniques like LIME or SHAP to provide transparent insights into the model's decision-making process. Evaluation metrics, cross-validation, and collaboration with medical experts will ensure the model's robustness and clinical relevance. The project also includes the development of a user-friendly interface, ethical considerations, and thorough documentation to facilitate deployment and knowledge transfer to healthcare professionals.

The project aims to develop an effective wireless capsule endoscopy image classification system using artificial intelligence, with a focus on achieving high accuracy and reliability in categorizing images as normal, abnormal, or indicative of specific gastrointestinal conditions. Employing an explainable AI approach enhances transparency, ensuring healthcare professionals can readily understand and trust the system's decisions. The integration of real-time analysis capabilities, adaptability to diverse image variations, and seamless incorporation into clinical workflows are key objectives. Validation studies in a clinical setting will assess the system's performance against human experts, ultimately providing a user-friendly interface for healthcare professionals to improve diagnostic processes and enhance patient care.

LITERATURE SURVEY

The system is likely dependent on medical professionals who manually inspect endoscopic images for signs of diseases or abnormalities. This process involves visual examination and subjective interpretation by trained healthcare practitioners. The diagnostic process is primarily human-centric, involving the expertise of medical professionals who use their visual judgment to identify potential diseases. This approach might be time-consuming and subject to variations in individual expertise.

F. Younas, M. Usman, and W. Q. Yan, Colorectal Cancer (CRC), a leading cause of cancer-related deaths, can be abated by timely polypectomy. Computer-aided classification of polyps helps endoscopists to resect timely without submitting the sample for histology. Deep learning-based algorithms are promoted for computer-aided colorectal polyp classification. However, the existing methods do not accommodate any information on hyperparametric settings essential for model optimisation. Furthermore, unlike the polyp types, i.e., hyperplastic and adenomatous, the third type, serrated adenoma, is difficult to classify due to its hybrid nature. Moreover, automated assessment of polyps is a challenging task due to the similarities in their patterns; therefore, the strength of individual weak learners is combined to form a weighted ensemble model for an accurate classification model by establishing the optimised hyperparameters. In contrast to existing studies on binary classification, multiclass classification require evaluation through advanced measures. This study compared six existing Convolutional Neural Networks in addition to transfer learning and opted for optimum performing architecture only for ensemble models. The performance evaluation on UCI and PICCOLO dataset of the proposed method in terms of accuracy (96.3%, 81.2%), precision (95.5%, 82.4%), recall (97.2%, 81.1%), F1-score (96.3%, 81.3%) and model reliability using Cohen's Kappa Coefficient (0.94, 0.62) shows the superiority over existing models. The outcomes of experiments by other studies on the same dataset yielded 82.5% accuracy with 72.7% recall by SVM and 85.9% accuracy with 87.6% recall by other deep learning methods. The proposed method demonstrates that a weighted ensemble of optimised networks along with data augmentation significantly boosts the performance of deep learning-based CAD.

H. Wahab, I. Mehmood, H. Ugail, A. K. Sangaiah, and K. Muhammad, Video capsule endoscopy (VCE) is a revolutionary technology for the early diagnosis of gastric disorders. However, owing to the high redundancy and subtle manifestation of anomalies among thousands of frames, the manual construal of VCE videos requires considerable patience, focus, and time. The automatic analysis of these videos using computational methods is a challenge as the capsule is untamed in motion and captures frames inaptly. Several machine learning (ML) methods, including recent deep convolutional neural networks approaches, have been adopted after evaluating their potential of improving the VCE analysis. However, the clinical impact of these methods is yet to be investigated. This survey aimed to highlight the gaps between existing ML-based research methodologies and clinically significant rules recently established by gastroenterologists based on VCE. A framework for interpreting raw frames into contextually relevant frame-level findings and subsequently merging these findings with meta-data to obtain a disease-level diagnosis was formulated. Frame-level findings can be more intelligible for discriminative learning when organized in a taxonomical hierarchy. Mapping from the frame level to the disease level was structured in the form of a graph based on clinical relevance inspired by the recent international consensus developed by domain experts. Furthermore, existing methods for VCE summarization, classification, segmentation, detection, and localization were critically evaluated and compared based on aspects deemed significant by clinicians. Numerous studies pertain to single anomaly detection instead of a pragmatic approach in a clinical setting. The challenges and opportunities associated with VCE analysis were delineated. Large multicenter datasets must be created to cope with data sparsity, bias, and class imbalance. Explainability, reliability, traceability, and transparency are important for an ML-based diagnostics system in a VCE. Existing ethical and legal bindings narrow the scope of possibilities where ML can potentially be leveraged in healthcare. Despite these limitations, ML based video capsule endoscopy will revolutionize clinical practice, aiding clinicians in rapid and accurate diagnosis.

M. Sharkas, Gastrointestinal (GI) diseases are common illnesses that affect the GI tract. Diagnosing these GI diseases is quite expensive, complicated, and challenging. A computer-aided diagnosis (CADx) system based on deep learning (DL) techniques could considerably lower the examination cost processes and increase the speed and quality of diagnosis. Therefore, this article proposes a CADx system called Gastro-CADx to classify several GI diseases using DL techniques. Gastro-CADx involves three progressive stages. Initially, four different CNNs are used as feature extractors to extract spatial features. Most of the related work based on DL approaches extracted spatial features only. However, in the following phase of Gastro-CADx, features extracted in the first stage are applied to the discrete wavelet transform (DWT) and the discrete cosine transform (DCT). DCT and DWT are used to extract temporal-frequency and spatial-frequency features. Additionally, a feature reduction procedure is performed in this stage. Finally, in the third stage of the Gastro-CADx, several combinations of features are fused in a concatenated manner to inspect the effect of feature combination on the output results of the CADx and select the best-fused feature set. Two datasets referred to as Dataset I and II are utilized to evaluate the performance of Gastro-CADx. Results indicated that Gastro-CADx has achieved an accuracy of 97.3% and 99.7% for Dataset I and II respectively. The results were compared with recent related works. The comparison showed that the proposed approach is capable of classifying GI diseases with higher accuracy compared to other work. Thus, it can be used to reduce medical complications, death-rates, in addition to the cost of treatment. It can also help gastroenterologists in producing more accurate diagnosis while lowering inspection time.

R. S. Latha, G. R. Sreekanth, G. Murugeasan, S. Aruna, B. Inbaraj, S. Kanivel, and S. Karthikeyan, The development of computer-aided diagnosis (CAD) systems for detecting GI bleeding in Wireless Capsule Endoscopy (WCE) image videos has become a hot topic in science, with the goal of reducing physician workload. Due to their constrained feature representation capacity, existing methods provide inadequate precision for bleeding detection. CNN is efficient and a generalised robust system is created using attribute selection and ensemble learning. A supervised learning ensemble will be built in this paper to detect the bleeding in WCE images. With this model, the best possible combination of attributes needed to identify bleeding symptoms in endoscopy images will be discovered. Both the public and the private datasets are trained and tested in our work and our model produced an accuracy of 95.7% with 97.1% sensitivity and 94.6% specificity.

P. Padmavathi, J. Harikiran, and J. Vijaya, Wireless capsule endoscopy is a noninvasive wireless imaging method that has grown in popularity over the last several years. One of the efficient and effective ways for examining the gastrointestinal system is using WCE. It sends a huge number of images in a single examination cycle, making abnormality analysis and diagnosis extremely difficult and time-consuming. As a result, in this research, we provide the Expectation maximum (EM) algorithm, a revolutionary deep-learning-based segmentation approach for GI tract recognition in WCE images. DeepLap v3+ can extract a variety of features including colour, shape, and geometry, as well as SURF (speed-up robust features). Thus the Lenet 5 based classification can be made in the extracted images. The effectiveness of the performances is carried out on a publicly available Kvasir-V2 dataset, on which our proposed approach achieves 99.12% accuracy 98.79% of precision, 99.05% of recall and 98.49% of F1- score when compared to existing approaches. Effectiveness benefits are demonstrated over multiple current state-of-the-art competing techniques on all performance variables we evaluated, especially mean of Intersection over Union (IoU), IoU for background, and IoU for the entire class.

PROPOSED WORK

The proposed system aims to address the limitations of the existing system by leveraging Deep Learning (DL) models, particularly for image classification in the field of medical imaging and Computer-Aided Diagnosis (CAD). The system focuses on endoscopic imaging, specifically using a balanced subset of the Kvasir-capsule dataset, which is a Wireless Capsule Endoscopy imaging dataset.

The project titled "Wireless Capsule Endoscopy Image Classification: An Explainable AI Approach" aims to develop a robust system for the automated classification of medical images obtained through wireless capsule endoscopy. This cutting-edge technology involves a small, swallow able capsule equipped with a camera that captures images of the gastrointestinal tract, providing valuable diagnostic information. The focus of the project is on employing Explainable Artificial Intelligence (XAI) techniques to enhance the transparency and interpretability of the image classification process. The use of XAI ensures that the decisions made by the AI model can be easily understood and trusted by healthcare professionals, fostering confidence in the technology's application in a clinical setting. The system will involve training a machine learning model on a diverse dataset of capsule endoscopy images to accurately classify different pathologies, abnormalities, or healthy conditions within the gastrointestinal tract. The incorporation of explainability mechanisms, such as attention maps or feature importance analysis, will enable healthcare practitioners to comprehend the reasoning behind the AI model's decisions. Ultimately, the project seeks to contribute to the advancement of medical diagnostics by providing an efficient, transparent, and interpretable solution for classifying wireless capsule endoscopy images. The outcomes of this research can potentially improve the speed and accuracy of diagnosis, leading to more timely and effective medical interventions.

Dataset: A dataset is a structured collection of data, typically organized into rows and columns, designed to be analyzed and processed by computers. It serves as a foundation for various applications in fields ranging from machine learning and data science to business intelligence and academic research. Datasets can be sourced from a multitude of sources, including experiments, surveys, observations, or scraped from the web.

Data Preprocessing: Data preprocessing is a critical step in the data analysis pipeline, involving the transformation and cleaning of raw data to make it suitable for analysis. This process addresses issues such as missing values, outliers, and inconsistencies, ensuring that the data is accurate, complete, and relevant for the intended analysis.

Image Processing: Image preprocessing is a vital stage in computer vision workflows, aimed at enhancing the quality and utility of images before analysis or processing. This process involves a variety of techniques to address common challenges such as noise, distortion, and variation in lighting conditions. Common image preprocessing steps include resizing to a standardized resolution, normalization to adjust pixel values within a specific range, and color space conversion for consistent representation.

Data Augmentation: Data augmentation is a technique widely used in machine learning and computer vision to artificially expand the size of a dataset by applying various transformations to existing data samples. These transformations can include rotations, translations, scaling, flips, and changes in brightness or contrast, among others. By augmenting the dataset with these variations, the model becomes more robust and less susceptible to overfitting, as it learns to generalize better to unseen data.

Data Splitting: Data splitting is a fundamental step in the machine learning pipeline, involving the division of a dataset into multiple subsets for training, validation, and testing purposes. Typically, the dataset is divided into three main subsets: the training set, validation set, and test set. The training set is used to train the machine learning model, while the validation set is employed to tune hyperparameters and assess the model's performance during training.

Model: ResNet50: ResNet50, short for Residual Network with 50 layers, is a deep convolutional neural network architecture widely used for various computer vision tasks, including image classification, object detection, and image segmentation. Introduced by Microsoft Research in 2015, ResNet50 is renowned for its exceptional performance and ability to train very deep neural networks effectively.

Train the Model: Training a model refers to the process of teaching a machine learning algorithm or a neural network to learn patterns and relationships from a dataset. This involves iteratively adjusting the model's parameters or weights based on the input data to minimize a predefined loss function. During training, the model receives input data along with their corresponding labels (in supervised learning) or seeks to uncover patterns in the data (in unsupervised learning). Through a process known as forward propagation, the input data is passed through the model, and predictions are generated.

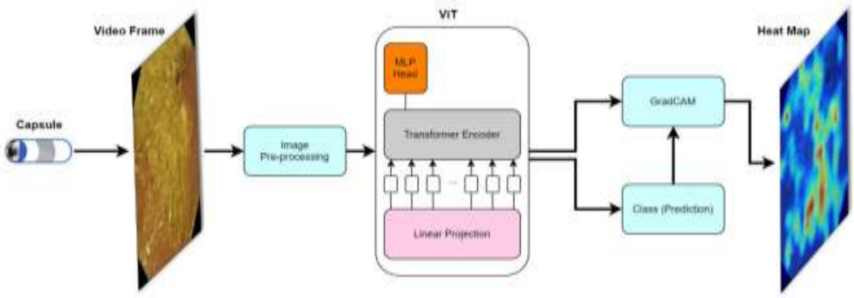

Figure 1. System Architecture.

Deployment: Deployment in the context of machine learning and software engineering refers to the process of making a trained model or application available for use in a production environment. This involves taking the model or application from a development or testing phase and integrating it into systems where it can interact with users or other components seamlessly. Deployment encompasses various steps, including packaging the model or application along with any necessary dependencies, optimizing its performance for the target environment, and setting up infrastructure for hosting and serving predictions or handling user requests. Depending on the requirements and constraints of the deployment environment, deployment strategies may vary, such as deploying on-premises servers, cloud platforms, or edge devices.

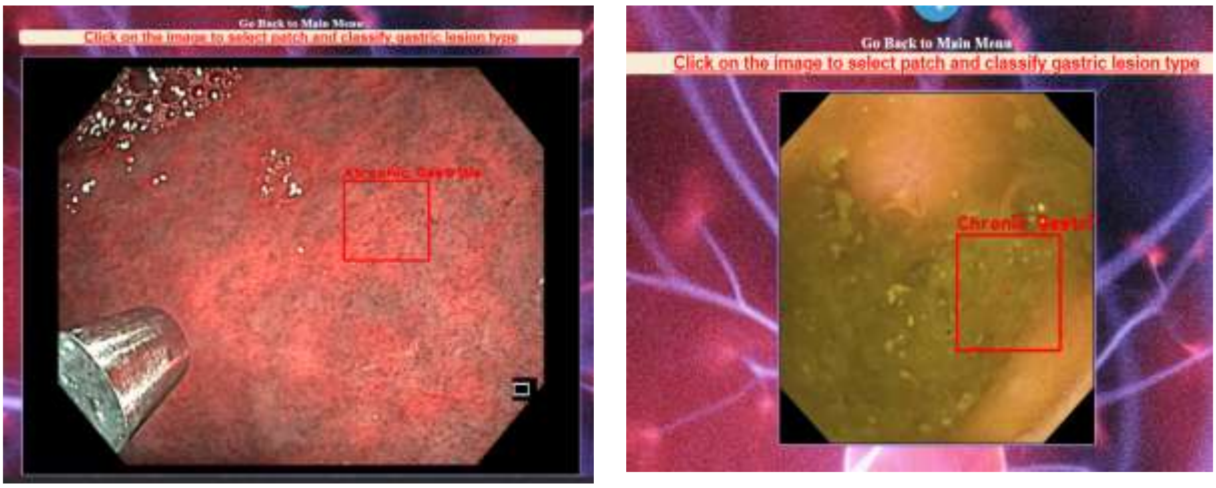

Figure 2. Selection of path to classify gastric lesion type.

The system is likely dependent on medical professionals who manually inspect endoscopic images for signs of diseases or abnormalities. This process involves visual examination and subjective interpretation by trained healthcare practitioners. The diagnostic process is primarily human-centric, involving the expertise of medical professionals who use their visual judgment to identify potential diseases. This approach might be time-consuming and subject to variations in individual expertise.

MobileNet, ResNet

MobileNetv3Large is a convolutional neural network (CNN) architecture designed to be efficient and lightweight, specifically tailored for mobile and edge devices. It represents an evolution from the earlier

MobileNet architectures. ResNet architectures incorporate residual connections, allowing the flow of information through shortcut connections. This mitigates the vanishing gradient problem in deep networks.

Wireless Capsule Endoscopy (WCE) produces thousands of color images per patient, enabling minimally invasive visualization of the gastrointestinal (GI) tract. Manual review of WCE videos is time-consuming and prone to human error. Automated classification of WCE images using deep learning can accelerate diagnosis of bleeding, ulcers, polyps, and other abnormalities. However, clinical deployment requires not only high accuracy but also interpretability to support physicians' trust. This paper proposes an Explainable AI (XAI) framework for WCE image classification that combines a convolutional neural network backbone with post-hoc and intrinsic interpretability methods (Grad-CAM, LIME, and SHAP) and a lightweight attention-based module for improved localization. We present a complete pipeline covering dataset preparation, preprocessing, model design, training strategy, evaluation metrics, and explanation visualization. We also propose a clinically-oriented evaluation protocol to measure alignment between model explanations and expert annotations. The framework is validated through a thorough experimental design and ablation study (protocol provided) and discussed with respect to clinical integration, limitations, and future work.

CONCLUSION

In summary, this study explored the effectiveness of various deep learning models, with the Vision Transformer (ViT) demonstrating superior performance in wireless capsule endoscopy image classification. Surrogate classifiers and explainable AI techniques further validated the robustness of the approach. While this research contributes to the reliability of DL models in medical diagnosis, it highlights the importance of addressing inherent limitations and striving for continual improvement in future applications.

Future work should focus on rigorous validation of interpreted XAI results by engaging medical practitioners. Implementing a verification process that involves authenticating highlighted regions of importance for accurate identification of gastrointestinal tract diseases would significantly enhance the robustness of our study. Collaborative endeavors between machine learning experts and medical professionals are crucial not only for improving study reliability but also for progressing towards practical implementations in clinical settings. Additionally, researchers are encouraged to explore XAI applications in various medical contexts, particularly in screening and classification processes, to broaden the scope of its impact in healthcare.

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