Hybrid Deep Learning Model for Automated Stroke Identification Using Neuroimaging

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***Abstract*— Stroke is one of the leading causes of death and long-term disability worldwide, making early diagnosis essential for improving patient survival and reducing permanent neurological damage. Recent advances in deep learning have provided new opportunities for analysing medical images with greater speed and accuracy. This study presents a Hybrid Deep Learning Model for Automated Stroke Identification Using Neuroimaging, designed to detect stroke from brain CT images at an early stage. The proposed framework combines image preprocessing, feature extraction, and a hybrid deep learning architecture to accurately distinguish stroke cases from normal brain scans. Relevant image features are selected to improve the learning process and enhance classification performance. The developed model is evaluated using standard performance measures, including accuracy, precision, recall, and F1-score, to ensure reliable diagnostic capability. Experimental results demonstrate that the proposed approach achieves superior performance compared with several conventional machine learning algorithms, providing more accurate and consistent stroke identification. The developed system can serve as an effective clinical decision support tool by assisting healthcare professionals in analysing neuroimages quickly, enabling timely diagnosis, appropriate treatment planning, and improved patient outcomes.**

***Keywords*—Stroke Identification, Neuroimaging, Hybrid Deep Learning, Brain CT Images, Medical Image Analysis, Automated Diagnosis, Feature Extraction, Image Classification, Artificial Intelligence in Healthcare, Clinical Decision Support System.**

I. INTRODUCTION

Stroke is one of the leading causes of death and long-term disability worldwide, affecting millions of people every year. It occurs when the blood supply to the brain is interrupted, resulting in damage to brain tissues due to a lack of oxygen and nutrients. According to the Centers for Disease Control and Prevention, rapid diagnosis and immediate treatment are essential for improving survival and reducing permanent neurological damage [2]. Recent studies have also highlighted the increasing global burden of stroke and emphasized the need for early detection strategies to improve healthcare outcomes [3]. Patients who survive a stroke often experience physical, cognitive, and communication impairments that significantly reduce their quality of life. Because of these serious consequences, healthcare professionals continue to seek accurate diagnostic methods that can identify stroke at its earliest stage. Early diagnosis not only improves treatment success but also reduces long-term healthcare costs and enhances patient recovery.

Stroke is generally categorized into ischemic and hemorrhagic types, each requiring different medical interventions. Ischemic stroke occurs when blood flow to the brain is blocked by a clot or narrowed artery, while hemorrhagic stroke results from the rupture of a blood vessel, causing bleeding inside the brain [4]. Correctly distinguishing between these stroke types is essential because treatment decisions depend heavily on accurate diagnosis. Traditional clinical assessment alone may not always provide sufficient information for rapid decision-making, particularly during emergency situations. Recent medical studies have demonstrated that combining neuroimaging with predictive analytics can significantly improve stroke diagnosis and patient management [5]. Large-scale clinical research has further shown that machine learning techniques can effectively identify patients at high risk of stroke by analysing complex healthcare data [6]. These developments have encouraged the adoption of intelligent diagnostic systems in modern healthcare.

Artificial intelligence has emerged as an effective technology for analysing medical images and supporting clinical diagnosis. Machine learning and deep learning algorithms can automatically identify complex patterns in brain CT and MRI scans that may not be easily recognized through manual examination. Early predictive models have shown promising results in identifying stroke patients using healthcare records and clinical information [1]. More recent studies have demonstrated that machine learning models can accurately estimate stroke probability, classify disease severity, and assist physicians in making informed treatment decisions

[7]. In emergency healthcare settings, intelligent prediction systems have also been developed to estimate stroke risk before hospital admission, enabling faster clinical response and improved patient care [8]. These advances indicate that AI-based diagnostic systems have considerable potential to improve stroke identification and reduce diagnostic delays.

Deep learning has significantly advanced medical image analysis by automatically extracting meaningful features directly from neuroimages. Convolutional Neural Networks (CNNs) and hybrid deep learning architectures have demonstrated excellent performance in analysing CT and MRI brain scans for disease detection. Image preprocessing techniques, including skull stripping and image enhancement, improve the quality of neuroimages before classification and contribute to more reliable predictions [9]. Researchers have also reported that deep learning models achieve high accuracy in predicting functional outcomes and detecting stroke-related abnormalities from medical images [12]. In addition, advanced image feature extraction methods have been developed to improve the classification of intracranial hemorrhage and other neurological conditions, leading to better diagnostic performance [18]. These developments show that deep learning has become an important tool for computer-aided medical diagnosis.

The proposed Hybrid Deep Learning Model for Automated Stroke Identification Using Neuroimaging is designed to provide an intelligent framework for accurate stroke diagnosis using brain CT images. Initially, the collected neuroimages undergo preprocessing to improve image quality and prepare them for analysis. A hybrid deep learning architecture then extracts important visual features and classifies each image as either normal or stroke-affected. The performance of the model is evaluated using standard metrics such as accuracy, precision, recall, and F1-score to ensure reliable diagnosis. Recent studies have demonstrated that optimized deep learning frameworks can accurately detect hemorrhagic lesions and improve automated analysis of CT brain images [16]. Furthermore, advanced deep learning models have shown improved performance in detecting intracranial hemorrhage from neuroimaging datasets, supporting their use in clinical decision support systems [19]. The proposed framework aims to assist healthcare professionals in achieving faster diagnosis and improving patient outcomes through intelligent medical image analysis.

II. RELATED WORK

Khosla et al., (2010) [1] proposed a machine learning framework for predicting stroke by analysing patient health records and clinical risk factors. The study aimed to identify individuals who were at a higher risk of developing stroke before symptoms became severe. Various patient characteristics were examined to improve prediction accuracy and support clinical decision-making. The authors showed that machine learning models can identify hidden relationships among medical features that are difficult to detect using conventional methods. Their approach achieved reliable prediction performance and demonstrated the value of intelligent healthcare systems. This research provides a strong foundation for applying machine learning in stroke prediction and supports the development of automated clinical decision support systems for early diagnosis and preventive healthcare.

Yang et al., (2021) [5] developed a machine learning model to predict stroke risk among patients with hypertension using medical big data. The study analysed multiple clinical features to identify important factors associated with stroke occurrence. Different machine learning algorithms were evaluated, and the proposed approach achieved reliable prediction accuracy. The authors concluded that predictive models can assist healthcare professionals in identifying high-risk patients at an early stage and support preventive treatment planning. Their work also highlighted the importance of analysing large healthcare datasets to improve disease prediction. This study demonstrates that machine learning can become an effective tool for improving stroke prevention and assisting physicians in making better clinical decisions.

Bacchi et al., (2020) [12] investigated the application of deep learning for predicting functional outcomes in patients with ischemic stroke. The study used medical imaging and clinical information to develop an intelligent prediction model capable of supporting treatment decisions. The authors demonstrated that deep learning algorithms could automatically extract meaningful features from medical data and provide accurate predictions. Their results indicated that AI-based systems could improve the consistency and speed of stroke assessment compared with traditional approaches. The research highlighted the growing role of deep learning in healthcare and its ability to assist clinicians during diagnosis and treatment planning. This work contributes to the development of intelligent medical decision support systems.

Phaphuangwittayakul et al., (2022) [16] proposed a deep learning framework for detecting different types of hemorrhagic brain lesions from CT images. The model combined image preprocessing and feature learning to improve classification performance and reduce diagnostic errors. Experimental results showed that the framework accurately identified hemorrhagic lesions while maintaining efficient processing speed. The authors emphasized that automated image analysis can support radiologists by providing rapid and reliable diagnostic assistance. Their study demonstrated the usefulness of deep learning in analysing brain CT images for emergency healthcare applications. This research provides valuable guidance for developing intelligent stroke identification systems using neuroimaging data.

Yeo et al., (2023) [19] evaluated several techniques to improve deep learning algorithms for detecting intracranial hemorrhage from CT head images. The study focused on enhancing model accuracy by optimizing image preprocessing and network training methods. The improved deep learning models produced better classification results with fewer prediction errors than earlier approaches. The authors concluded that accurate automated analysis of CT images can help clinicians detect brain hemorrhage more quickly and support timely medical intervention. Their findings demonstrate the importance of advanced deep learning techniques in neuroimaging applications and provide a useful reference for developing reliable AI-based stroke detection systems.

III. DATASET DETAILS

The dataset used in this project consists of brain CT neuroimages collected from patients with normal brain conditions and different types of stroke. Each image is labelled according to its corresponding diagnosis, allowing the deep learning model to learn the visual differences between healthy and stroke-affected brain scans. The dataset includes images representing ischemic stroke, hemorrhagic stroke, and normal cases, providing sufficient variation for reliable classification. Since medical image quality directly influences prediction performance, all CT scans are carefully examined to remove corrupted or low-quality samples before model training. The dataset is organized in a structured format so that each image and its associated class label can be efficiently processed. This collection of labelled neuroimages serves as the primary source for training and evaluating the proposed hybrid deep learning model for automated stroke identification.

Before model training, several preprocessing techniques are applied to improve the quality and consistency of the neuroimages. The CT images are resized to a fixed resolution and normalized to maintain uniform pixel intensity values throughout the dataset. Image enhancement is performed to improve important anatomical features, while unnecessary noise is reduced to increase classification accuracy. The processed dataset is then randomly shuffled to prevent training bias and divided into 70% training data and 30% testing data. Feature extraction and optimization are performed before classification to help the model focus on the most informative image characteristics. These preprocessing steps improve learning efficiency, enhance model generalization, and ensure reliable stroke identification on previously unseen brain CT images.

IV. PROPOSED METHODOLOGY

The proposed Hybrid Deep Learning Model for Automated Stroke Identification Using Neuroimaging follows a systematic approach for detecting stroke from brain CT images. Initially, the Brain_Data_Organised dataset is collected and examined to ensure that all neuroimages are correctly labelled as either normal or stroke-affected. During preprocessing, the CT images are resized, normalized, and enhanced to improve image quality while removing unnecessary variations and noise. The processed dataset is then randomly shuffled and divided into 80% training data and 20% testing data to enable effective model learning and unbiased evaluation. These preprocessing steps help the model extract meaningful image features and improve its overall classification performance. The prepared neuroimages provide the foundation for developing a reliable automated stroke detection system.

After preprocessing, different classification models, including K-Nearest Neighbour (KNN), Naïve Bayes, Support Vector Machine (SVM), GA-BiLSTM, and CNN-BiLSTM with an Attention mechanism, are trained and evaluated using the training dataset. The performance of each model is measured using accuracy, precision, recall, F1-score, and confusion matrix analysis. The hybrid CNN-BiLSTM Attention model achieves the best performance and is selected as the final prediction model. A graphical user interface allows users to upload new brain CT images for real-time stroke identification. The trained system analyses the uploaded neuroimage and classifies it as either Normal or Stroke, providing fast and reliable decision support for medical diagnosis.

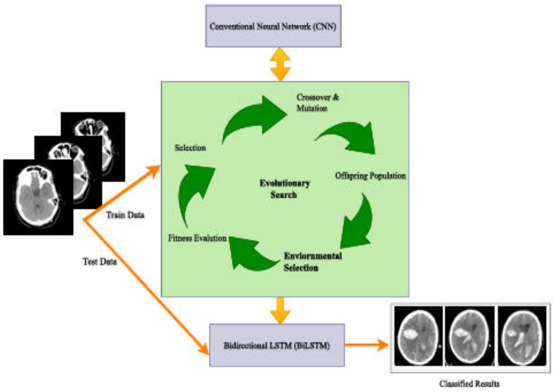

Figure [1]: Hybrid Deep Learning-Based Stroke Identification Architecture

Figure [1] shows the architecture of the proposed stroke identification system. Brain CT images are divided into training and testing data. The training images are processed using a CNN with evolutionary feature optimization, and the extracted features are classified using a BiLSTM model. Finally, the trained system predicts stroke from new CT images with improved accuracy.

V. RESULT AND DISCUSSION

The experimental evaluation confirms that the proposed Hybrid Deep Learning Model for Automated Stroke Identification Using Neuroimaging can accurately detect stroke from brain CT images. The collected neuroimage dataset was first preprocessed through image resizing, normalization, and enhancement to improve its quality before model training. After dividing the dataset into training and testing sets, several classification methods, including KNN, Naïve Bayes, Support Vector Machine (SVM), GA-BiLSTM, and the proposed CNN-BiLSTM model, were trained and evaluated. Performance was measured using accuracy, precision, recall, F1-score, and confusion matrix analysis. Among all the evaluated models, the proposed hybrid deep learning framework achieved the best overall performance by correctly identifying the majority of stroke and normal brain images with very few classification errors. The confusion matrix demonstrated a high number of correct predictions, indicating the robustness of the model. The developed application was further tested using unseen CT images, where it successfully classified the input scans and generated reliable diagnostic results. These findings demonstrate that the proposed framework can provide accurate, efficient, and dependable support for automated stroke identification in medical imaging.

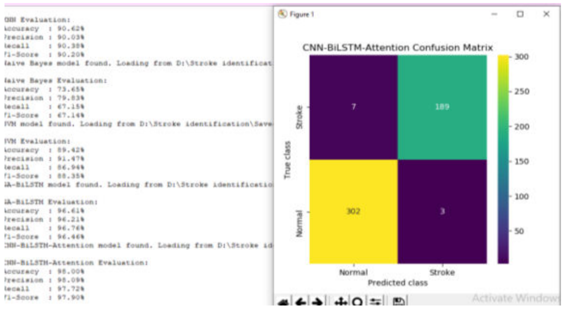

Figure [2]: Proposed CNN-BiLSTM-Attention Model Performance

Figure [2] illustrates the performance of the proposed CNN-BiLSTM-Attention model for stroke identification. The figure displays the model's evaluation metrics, including accuracy, precision, recall, and F1-score, along with the corresponding confusion matrix. The high number of correct classifications and minimal prediction errors demonstrate the effectiveness of the proposed hybrid deep learning model in accurately identifying stroke from brain CT images.

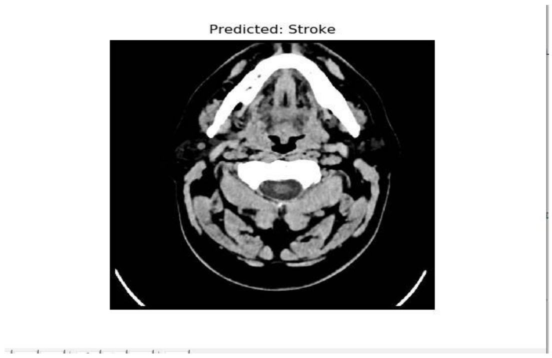

Figure [3]: Stroke Prediction Result

Figure [3] shows the prediction result generated by the proposed CNN-BiLSTM-Attention model after analysing a brain CT image. The uploaded neuroimage is processed by the trained deep learning framework, which classifies the scan as Stroke. This demonstrates the model's capability to provide fast and accurate stroke identification, supporting clinicians in timely diagnosis and treatment planning.

DISCUSSION

The findings of this study demonstrate that hybrid deep learning techniques can significantly improve the accuracy of stroke identification from neuroimaging data. The combination of CNN and BiLSTM enables the model to learn both detailed spatial information and high-level image patterns, leading to better classification performance than conventional machine learning approaches. Image preprocessing also played an important role by enhancing image quality and reducing unnecessary variations, allowing the model to focus on clinically relevant features. Performance comparisons showed that the proposed framework consistently achieved higher evaluation scores than traditional classifiers such as KNN, Naïve Bayes, and SVM. The confusion matrix further confirmed that only a small number of CT images were misclassified, demonstrating the reliability of the proposed approach. In addition, the user interface allows healthcare professionals to upload brain CT images and obtain prediction results within a short time, making the system practical for real-world clinical environments. Overall, the proposed framework provides an effective decision support tool that can assist clinicians in early stroke diagnosis, improve treatment planning, and contribute to better patient care through intelligent neuroimage analysis.

VI. CONCLUSION

The proposed Hybrid Deep Learning Model for Automated Stroke Identification Using Neuroimaging demonstrates that artificial intelligence can play an important role in improving the early diagnosis of stroke. By combining effective image preprocessing, optimized feature extraction, and a hybrid deep learning architecture, the system accurately identifies stroke from brain CT images. The experimental results show that the proposed framework achieves high accuracy, precision, recall, and F1-score, outperforming conventional machine learning methods such as KNN, Naïve Bayes, and Support Vector Machine. The integration of CNN and BiLSTM enables the model to learn complex image patterns more effectively, resulting in reliable and consistent classification performance. The developed system also provides a practical decision support tool that can assist healthcare professionals in analysing neuroimages quickly and making timely treatment decisions. Early identification of stroke has the potential to reduce complications, improve patient recovery, and support better clinical outcomes. In the future, the framework can be enhanced by training it on larger and more diverse neuroimaging datasets, incorporating additional medical imaging modalities such as MRI, and optimizing the model for real-time clinical deployment. These improvements can further strengthen its accuracy, scalability, and usefulness in modern healthcare environments.

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