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AI-Driven Multimodal Framework for Autoimmune Hepatitis Diagnosis Using Clinical and Histopathology Data

Akshay Bankar, Harshwardhani Kewate, Sahil Tandekar, Shejal Meshram
Dept. of Computer Science and EngineeringGurunanak Institute of Engineering and Technology Nagpur, India

Abstract: ***Autoimmune Hepatitis (AIH) is a chronic inflammatory liver disorder whose accurate diagnosis necessitates the concurrent evaluation of clinical, serological, and histopathological data. The diagnostic process remains inherently complex due to the requirement for expert interpretation of liver biopsy specimens and clinical reports, both time-intensive and prone to inter-observer variability. This paper presents an AI-driven multimodal diagnostic framework that integrates clinical text data with histopathological biopsy images to assist clinicians in the evaluation of AIH. The system is deployed as a web-based application that accepts structured patient records and biopsy images as inputs, processes them through a multimodal large language model (MLLM), and generates two forms of output: a clinician-oriented structured diagnostic support report and a simplified patient-facing explanation. Evaluation on simulated diagnostic scenarios demonstrates an overall diagnostic accuracy of 0.88, precision of 0.91, and recall of 0.85, with average inference time under one minute per case. These results underscore the potential of multimodal AI architectures to enhance diagnostic efficiency and improve patient communication in hepatology.***

Keywords: autoimmune hepatitis; multimodal artificial intelligence; medical image analysis; clinical decision support; large language models

I. INTRODUCTION

Autoimmune Hepatitis (AIH) is an immune-mediated liver disease characterized by persistent hepatic inflammation and progressive fibrosis that can advance to cirrhosis and liver failure if untreated [1]. Its pathogenesis involves loss of selftolerance against hepatocellular antigens, mediated by autoreactive T-lymphocytes in genetically susceptible individuals [2]. Clinically, AIH presents with considerable phenotypic heterogeneity, spanning a spectrum from asymptomatic biochemical abnormalities to acute liver failure, substantially complicating timely recognition.

The diagnosis of AIH relies on synthesis of clinical history, biochemical markers, autoantibody profiles, immunoglobulin levels, and liver biopsy findings. The International Autoimmune Hepatitis Group scoring system and the Simplified Criteria proposed by Hennes et al. [3] have codified these parameters; however, their application demands considerable clinical expertise and remains susceptible to inter-rater variability, particularly in histopathological assessment of interface hepatitis, rosette formation, and plasma cell infiltration.

The rapid evolution of artificial intelligence, particularly deep learning and natural language processing, has opened transformative avenues for medical diagnostics. CNNs have demonstrated high accuracy in classifying histopathological patterns [5], while transformer-based language models have shown proficiency in interpreting unstructured clinical narratives. However, the majority of existing AI diagnostic tools operate unimodally, processing either images or text in isolation, thereby failing to exploit diagnostic complementarity between these data sources.

Multimodal large language models (MLLMs) represent an architecturally significant advancement, enabling simultaneous processing of heterogeneous inputs within a unified representational space. Their application to hepatology, however, remains nascent. This paper addresses this gap by proposing an MLLM-based diagnostic support system that integrates clinical records and liver biopsy images for the evaluation of AIH, with the dual objective of augmenting diagnostic accuracy and improving patient communication.

II. RELATED WORK

Early computational approaches to liver pathology focused exclusively on image-based analysis. CNNs trained on digitized liver biopsies have demonstrated capacity to identify histological hallmarks of hepatic disease, including lobular inflammation, periportal necrosis, and fibrotic remodeling, with performance approaching expert pathologist concordance [5].

Attention-guided CNN architectures further enabled localization of pathologically relevant regions in whole-slide images, providing interpretable evidence for classification decisions.

Parallel lines of investigation have applied machine learning to structured and unstructured clinical data. NLP pipelines have been employed to extract diagnostic features from electronic health records, while gradient-boosted classifiers trained on laboratory parameters have shown utility in distinguishing AIH from other inflammatory liver conditions. These text-based approaches, however, operate independently of histopathological evidence, limiting their diagnostic completeness.

The emergence of multimodal learning has facilitated coprocessing of imaging and textual modalities. Multimodal architectures combining vision encoders with language models have achieved strong performance in radiology report generation, ophthalmology screening, and oncological staging [4]. The MedPaLM multimodal system and related foundation models have demonstrated broad-spectrum clinical reasoning capability, though their deployment in specialist hepatology contexts remains limited [4].

Moor et al. [4] highlight the potential for generalist medical AI models grounded in multimodal data, yet note that domain-specific fine-tuning and structured output generation remain critical prerequisites for clinical adoption. The system proposed in this paper addresses these requirements within the hepatology domain, with particular focus on AIH diagnosis.

III. SYSTEM ARCHITECTURE AND METHODOLOGY

The proposed system is implemented as a client–server web application comprising a frontend interface for clinical data submission, a backend processing server, and a multimodal inference engine.

A. Data Input Module

Clinicians interact with the system through a structured web interface accepting two categories of input. Patient clinical information is submitted either via a structured form or as an uploaded PDF document containing laboratory reports, clinical history, and autoantibody profiles. Digitized liver biopsy images are uploaded for histopathological analysis. Input validation ensures completeness of essential clinical fields prior to processing.

B. Backend Processing and Data Encoding

The backend server receives multipart requests containing both textual and image data. Uploaded PDF documents are parsed to isolate clinically relevant fields, including alanine aminotransferase (ALT), aspartate aminotransferase (AST), immunoglobulin G (IgG) concentrations, and autoantibody titres. Biopsy images are preprocessed through normalization and resizing operations to conform to model input requirements. Textual and visual inputs are subsequently encoded into a unified latent representation suitable for joint inference.

C. Multimodal Inference Engine

A multimodal large language model serves as the core inference component. The model receives encoded clinical text and biopsy image representation as a combined prompt, performing joint reasoning over both modalities to assess AIH diagnostic likelihood. The inference process evaluates histopathological evidence of interface hepatitis, serological autoantibody patterns, and biochemical markers of hepatic injury, generating probability estimates alongside a structured narrative assessment aligned with established diagnostic criteria [3].

D. Output Generation

The system produces two distinct output documents. The primary output is a clinician-oriented diagnostic report presenting a differential diagnosis, supporting evidence from both input modalities, and a structured assessment consistent with the Simplified AIH Criteria scoring framework. The secondary output is a patient-facing explanation in plain language, designed to communicate diagnostic findings accessibly and support shared decisionmaking. Both outputs are rendered within the web interface and available for download.

IV. RESULTS AND DISCUSSION

The proposed system was evaluated against a curated set of simulated clinical scenarios representing diverse AIH manifestations, including acute presentation, chronic indolent disease, and overlap syndrome cases. Each scenario comprised synthesized patient records and annotated biopsy images, with ground-truth diagnostic labels established through consensus expert annotation.

Quantitative evaluation yielded an overall diagnostic accuracy of 0.88, with precision of 0.91 and recall of 0.85 across the test set.

The higher precision relative to recall indicates that the system exhibits a conservative diagnostic posture, generating fewer false positive AIH diagnoses at the cost of a modest increase in false negatives. In a clinical context where confirmatory biopsy typically follows a positive diagnostic flag, this characteristic is preferentially acceptable relative to excessive false positive rates.

Average inference time per case was under one minute, encompassing document parsing, image preprocessing, model inference, and report rendering. This throughput is compatible with prospective integration into outpatient hepatology workflows as a pre-consultation screening tool.

Qualitative assessment of generated diagnostic reports demonstrated coherent integration of multimodal evidence. In cases where histopathological and serological findings were concordant, the system produced well-calibrated probability estimates. Discordant cases, such as drug-induced liver injury with autoimmune features, elicited broader differential diagnoses, reflecting appropriate diagnostic uncertainty. Patient-facing outputs were assessed as clear, non-alarming, and free of clinical jargon.

Limitations include the use of simulated rather than real patient data, a relatively small test set, and the absence of prospective clinical validation. The performance metrics reported should therefore be interpreted as indicative of proofof-concept feasibility rather than clinical-grade benchmarks.

V. CONCLUSION

This paper presents an AI-driven multimodal diagnostic support framework for autoimmune hepatitis that integrates clinical text records with histopathological biopsy images through a unified MLLM inference pipeline. The system demonstrates technically viable performance on simulated diagnostic scenarios, achieving 0.88 accuracy and sub-minute inference latency. Its dual-output architecture addresses both clinical decision support and patient health communication requirements.

The principal contribution lies in the application of multimodal AI to a diagnostically challenging and understudied hepatological condition, establishing a methodological foundation for subsequent real-world validation.

VI. FUTURE SCOPE

Future work will prioritize prospective validation using real-world clinical datasets sourced from hepatology centers, with ethics board approval and informed patient consent. Expansion of the training and evaluation corpus to include larger, demographically diverse biopsy image collections will be essential to assess model robustness and generalizability across histological staining protocols.

Integration with hospital electronic health record systems via HL7 FHIR-compliant APIs would enable deployment within existing clinical information infrastructure. Model interpretability enhancements, including attention visualization over biopsy images and evidence attribution for textual clinical features, will be pursued to increase clinician trust and facilitate regulatory compliance. Broader application to related hepatic conditions, such as primary biliary cholangitis and non-alcoholic steatohepatitis, will also be explored.

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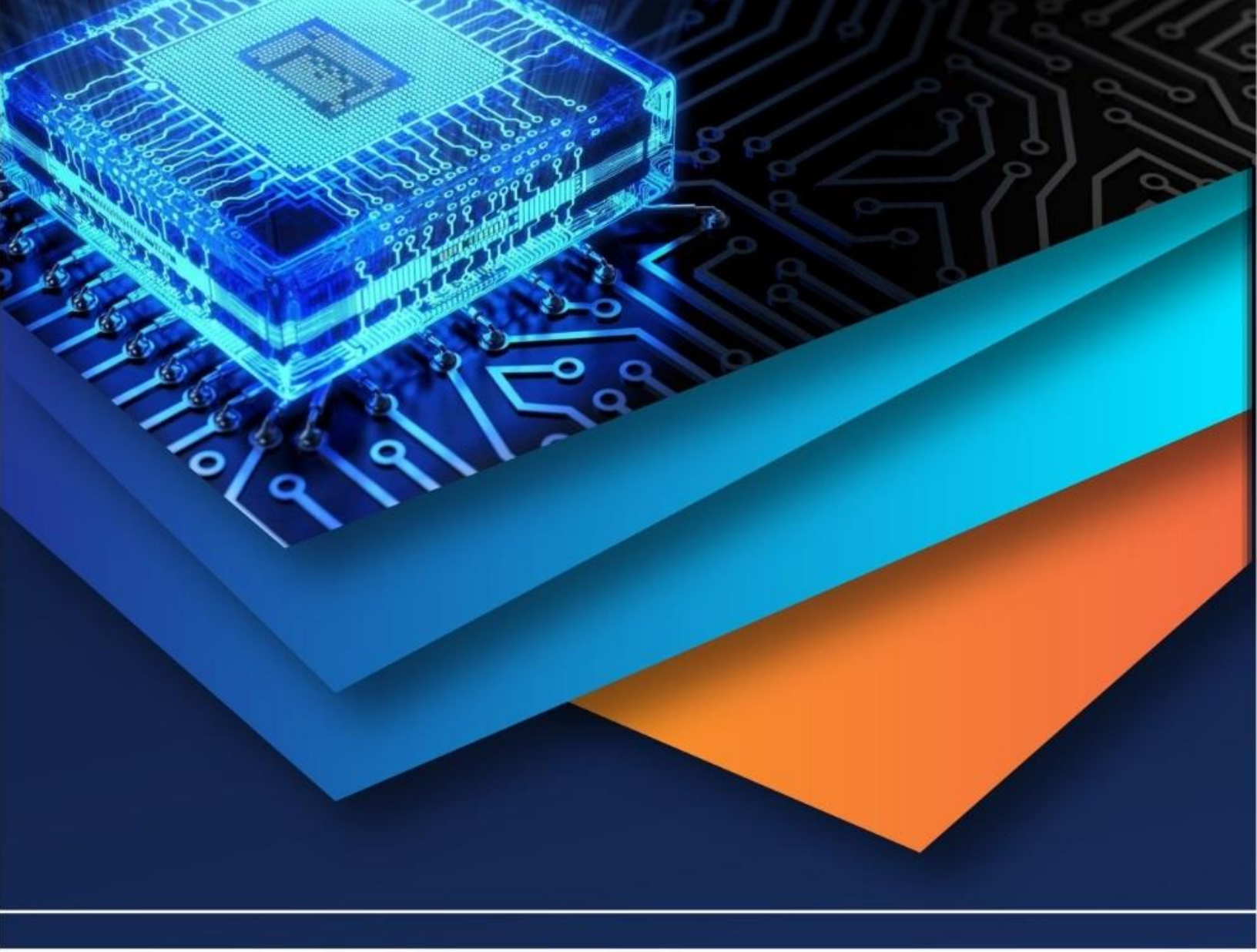

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