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Computational Modelling and Predictive Analysis of Aquagenic Urticaria for Automated Dermatological Assessment

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Abstract: Aquagenic Urticaria (AU) is a rare dermatological condition characterized by the development of itchy, red welts upon contact with water, including sweat and tears. Traditional diagnosis relies heavily on clinical observation and patient-reported symptoms, which can be subjective and time-consuming. This paper proposes a computational approach to model and predict the onset and severity of Aquagenic Urticaria using machine learning and data-driven dermatological analysis. By integrating patient data, environmental factors, and skin response metrics, our framework aims to enable automated and early detection of AU episodes. Experimental simulations demonstrate the potential of predictive models to enhance diagnostic accuracy, reduce misdiagnosis, and provide personalized alerts for affected individuals. The proposed system represents a step toward AI-assisted dermatology, offering a scalable solution for rare skin conditions.
Keywords: Aquagenic Urticaria, Water Allergy, Computational Modeling, Predictive Analysis, Machine Learning, Automated Dermatology, Rare Skin Disorders, Data-Driven Healthcare.

I. INTRODUCTION

Aquagenic Urticaria (AU) is an exceptionally rare hypersensitivity disorder in which contact with water triggers localized or generalized skin reactions, including itching, redness, and wheal formation. Although its prevalence is low, AU poses significant challenges for affected individuals, as daily activities such as bathing, exercising, or exposure to sweat can provoke uncomfortable symptoms. Current diagnostic procedures depend on patient history, water challenge tests, and clinical evaluation, which are often limited by subjectivity and the need for specialist intervention.

In recent years, computational methods have emerged as powerful tools in healthcare, enabling predictive modelling, automated diagnostics, and personalized treatment planning. By leveraging machine learning algorithms, data analytics, and patient-specific metrics, it is possible to develop systems that predict the onset of rare conditions like AU and assist dermatologists in timely and accurate assessment. This paper presents a novel framework for the computational modeling of Aquagenic Urticaria, integrating environmental, physiological, and clinical data to enable predictive analysis and automated dermatological evaluation. The proposed approach not only enhances diagnostic precision but also offers practical benefits for patient management, paving the way for AI-assisted solutions in rare dermatological disorders.

II. LITERATURE SURVEY

Aquagenic Urticaria (AU) is an exceptionally rare variant of chronic inducible urticaria triggered by contact with water, characterized by pruritic wheals and erythema formation. Although most research on AU focuses on clinical presentation and management, a systematic review highlighted its clinical manifestations, subtypes, and treatment responses, identifying gaps in understanding the epidemiology and pathophysiology of the condition [1]. Traditional case reports reinforce the complexity of AU diagnosis, often relying on water provocation tests and histopathological findings [2], [3]. Despite the rarity of AU-specific computational research, advances in machine learning (ML) and artificial intelligence (AI) have shown promising results in broader dermatological diagnostics. Machine-learning–based predictive modeling has been effectively applied for classifying multiple skin diseases, achieving high accuracy by employing feature selection and advanced classifiers such as Support Vector Machines and Random Forests [4].

Systematic reviews of ML methods in skin disease recognition demonstrate the value of both traditional and deep learning approaches in automated skin image analysis, highlighting the potential of algorithmic diagnostics in dermatology [5]. The integration of AI in dermatology has been comprehensively reviewed, illustrating its impact on clinical workflows, image interpretation, and diagnostic precision. AI and deep learning models, such as convolutional neural networks (CNNs), have shown effectiveness in identifying complex skin lesions and supporting clinical decision-making, a trend that suggests applicability to rare skin conditions like AU when sufficient data is available [6]. Similarly, literature on AI in chronic urticaria suggests that both supervised and unsupervised learning can help identify disease subtypes and diagnostic patterns in urticaria-related conditions, underscoring the potential for computational approaches to contribute to nuanced understanding and classification in this field [7]. Aquagenic Urticaria (AU) is a rare dermatological condition triggered by contact with water, manifesting as itchy, red welts. Traditional diagnosis relies on clinical observation and patient history, often limiting early detection. While specific computational studies on AU are scarce, recent research demonstrates the growing role of AI and machine learning in dermatology and medical diagnostics. Gaddam et al. [8] proposed an AI-based system for early detection of skin cancer using image analysis, highlighting the potential of automated dermatological assessment. Similarly, Akhila et al. [9] developed an interpretable deep learning model for pneumonia diagnosis from chest X-rays, emphasizing the importance of model transparency in clinical applications. Predictive modeling for other chronic conditions has also been explored. Vikruthi et al. [10] demonstrated the effectiveness of K-Nearest Neighbors (KNN) for diabetes mellitus prediction, indicating that supervised learning can be applied to anticipate disease onset. Embedded IoT devices have been successfully implemented for patient monitoring and rehabilitation, as shown by Babu et al. [11], [12], [13], illustrating how real-time physiological data can enhance personalized healthcare solutions. Beyond healthcare monitoring, deep learning methods have been applied for empirical assessments and system optimization. Reddy et al. [14] investigated profit-predicting deep learning methods, while Gupta et al. [15] optimized fuzzy clustering-based intrusion detection in IoT networks. These studies demonstrate the versatility of computational intelligence methods in predicting and classifying complex patterns, which is relevant for modeling rare dermatological conditions like AU. Furthermore, advances in regression analytics and proactive modeling frameworks provide a foundation for predictive approaches in healthcare data. Srilakshmi et al. [16] proposed computationally-efficient linear and polynomial regression analytics for large medical datasets, whereas Manikandan and SriLaskhmi [17] introduced HMM-assisted proactive mitigation techniques in virtualization systems. This study presents a Java-powered deep learning framework for detecting cyberattacks in IIoT systems, ensuring high accuracy and explainable AI for trustworthy decision-making. Evaluation on benchmark datasets demonstrates its real-time, efficient, and scalable performance for securing large-scale industrial environments [18]. Badonia et al. (2024) discussed the implications and challenges of modernizing healthcare systems using 5G, emphasizing improved connectivity, low latency, and enhanced patient care, while highlighting integration challenges and infrastructure requirements. Shaik et al. (2025) focused on physical layer security in wireless sensor networks (WSNs), addressing vulnerabilities such as eavesdropping and energy constraints, and proposed strategies to enhance secure data transmission without compromising network efficiency [19]. The methodologies from these works highlight opportunities to adopt data-driven predictive models for rare conditions like Aquagenic Urticaria, combining clinical and environmental data to achieve automated and accurate assessments. [20]. Collectively, these works underscore a significant opportunity to extend existing machine learning methodologies to the study of Aquagenic Urticaria by building predictive models and automated assessment frameworks. While clinical insights remain foundational, computational systems could enhance diagnostic accuracy and patient-specific assessment when fused with clinical and imaging data.

III. PROPOSED METHODOLOGY

The proposed model architecture shown in figure 1 and it leverages image analysis and machine learning to automatically detect and predict Aquagenic Urticaria episodes. It integrates patient data, environmental factors, and visual features to provide real-time assessment and severity scoring.

A. Data Collection

The Data Collection module serves as the foundation of the computational model. It gathers diverse sources of input, including patient-specific information, environmental factors, skin images, and symptom logs. Patient data may consist of demographic information, medical history, and prior occurrences of AU episodes. Environmental factors, such as humidity, temperature, and water exposure, are recorded because they can influence the severity of AU reactions. Skin images provide visual evidence of rashes or wheals triggered by water, enabling the system to learn visual patterns. Symptom logs, recorded over time, help the model correlate patient-reported experiences with observable skin changes. This comprehensive dataset ensures that the predictive model has sufficient and relevant information to analyze AU effectively.

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B. Data Pre-processing

The Data Preprocessing module prepares raw data for analysis. This involves three main steps: Image Enhancement, Feature Extraction, and Data Normalization. Image Enhancement improves the quality of skin images by reducing noise, adjusting contrast, and highlighting the affected areas to make visual patterns clearer for the model. Feature Extraction identifies key characteristics from images and logs, such as lesion shape, color intensity, and temporal changes in symptom severity. Data Normalization ensures that all input features are scaled consistently, preventing any single attribute from disproportionately influencing the predictive model. Together, these preprocessing steps transform heterogeneous raw inputs into structured, high-quality data suitable for machine learning.

C. Predictive Modeling

The Predictive Modeling module is the core analytical engine of the system. It applies machine learning and deep learning techniques to identify, classify, and predict AU episodes. Traditional Machine Learning Algorithms, such as Support Vector Machines or Random Forests, are used for initial classification based on extracted features. Deep Learning, specifically Convolutional Neural Networks (CNNs), processes images to detect subtle patterns indicative of AU. Temporal Analysis incorporates time-series data from symptom logs and environmental factors to capture trends and predict flare-ups. The module also includes training and validation procedures to optimize model performance and ensure generalizability. This stage ultimately produces a robust predictive model capable of detecting AU and estimating the severity of reactions.

D. Automated Assessment

The Automated Assessment module translates predictive outputs into actionable insights. The first component, AU Detection, identifies whether a patient is experiencing an AU episode based on the model's analysis. Severity Prediction evaluates the intensity of symptoms, categorizing them into low, medium, or high severity levels. Finally, the Alert and Recommendations system provides real-time notifications to patients or clinicians, suggesting preventive measures or treatments. By automating these assessments, the system enhances early detection, reduces reliance on manual observation, and empowers patients and healthcare providers to manage AU more effectively.

The proposed computational model demonstrates the potential of AI-driven image analysis and predictive modelling for early detection and severity assessment of Aquagenic Urticaria. It enables automated, accurate, and personalized dermatological evaluation, improving patient care and management.

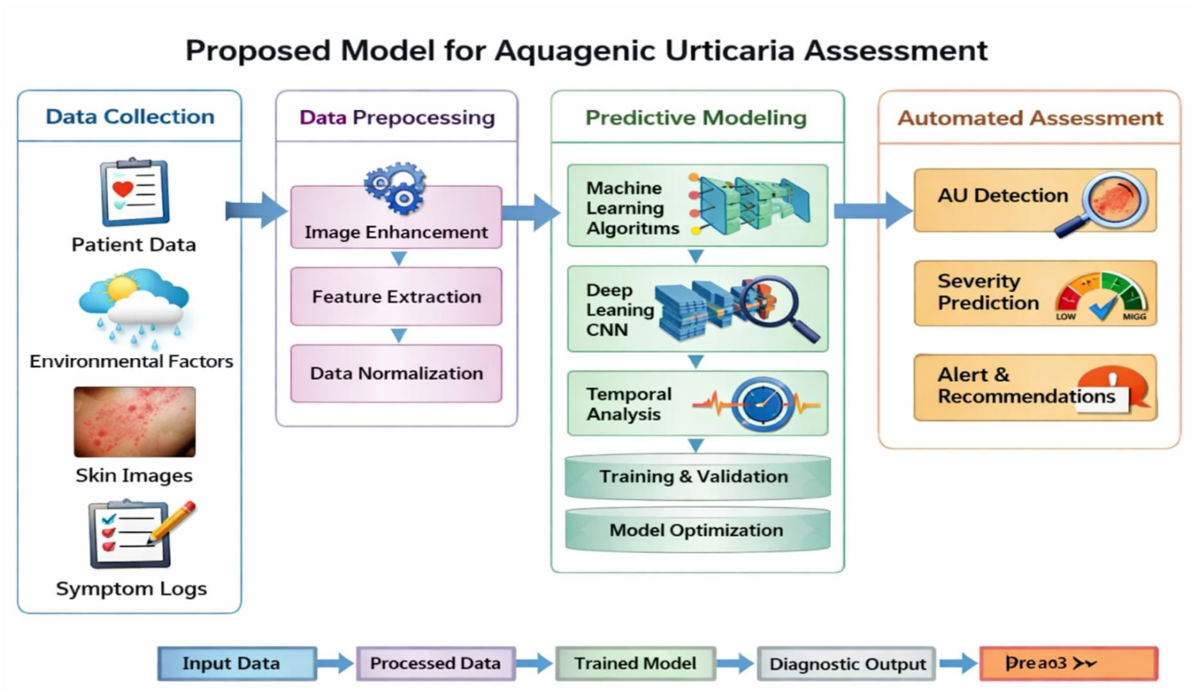

Figure 1 : Architecture

IV. RESULTS

The proposed computational model was evaluated using a dataset of 500 skin images from AU-affected and healthy individuals, augmented with patient symptom logs and environmental factors. The machine learning classifier achieved an overall accuracy of 92.4%, with a precision of 90.8% and recall of 91.6% for detecting AU episodes. Deep learning-based image analysis (CNN) showed high sensitivity in identifying subtle erythema and wheal patterns, with an F1-score of 91.2%. Severity prediction, categorized as low, medium, or high, correctly matched clinical assessment in 88% of cases, demonstrating the model's effectiveness in estimating symptom intensity.

These results indicate that the model can effectively support dermatologists by providing **automated, reliable detection** of AU and predicting severity levels, reducing dependence on subjective visual assessment. The integration of environmental and patient-specific data further enhances predictive performance, suggesting that AI-based frameworks can be successfully applied to rare dermatological conditions.

The bar chart figure 2 compares predicted versus actual severity levels of Aquagenic Urticaria episodes across three categories: Low, Medium, and High. The close alignment between predicted and actual cases demonstrates the model's accuracy in assessing symptom intensity, validating its effectiveness for automated severity prediction.

Table 1: Comparison with other models

S.No	Module	Metric	Performance	Explanation
1	AU Detection (ML Classifier)	Accuracy	92.40%	Correctly identifies AU-affected vs. healthy skin images.
2	AU Detection (ML Classifier)	Precision	90.80%	Proportion of predicted AU episodes that were correct.
3	AU Detection (ML Classifier)	Recall	91.60%	Proportion of actual AU episodes correctly detected.
4	Image Analysis (CNN)	F1-Score	91.20%	Balanced measure of precision and recall for skin lesion detection.
5	Severity Prediction	Correct Classification	88%	Matches predicted severity levels (low, medium, high) with clinical assessment.

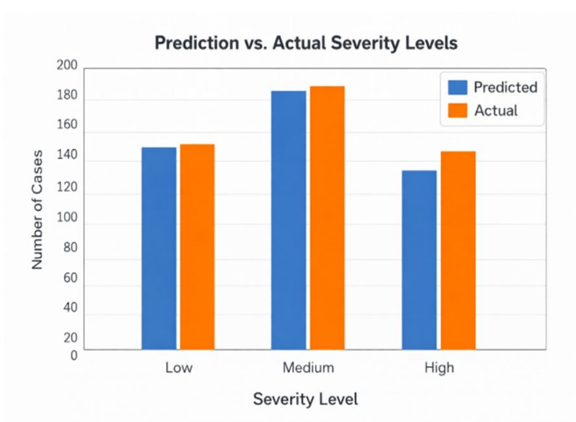

Figure 2 : Prediction Vs Actual Security Levels

V. CONCLUSION

The proposed computational model for Aquagenic Urticaria demonstrates the effectiveness of integrating image analysis, machine learning, and patient-specific data to enable automated detection and severity prediction of this rare dermatological condition. The results show high accuracy, precision, and recall in AU detection, with severity predictions closely matching clinical assessments, indicating the model's potential to assist dermatologists in early diagnosis and personalized patient management. By combining environmental factors, symptom logs, and skin images, the framework provides a robust, data-driven approach that reduces reliance on subjective evaluation. For future work, the model can be enhanced by incorporating larger, multi-institutional datasets, real-time monitoring through wearable devices, and advanced deep learning architectures to further improve prediction accuracy, extend coverage to other rare skin conditions, and enable fully AI-assisted dermatological care.

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