International Journal Software Engineering and Computer Science (IJSECS)
5 (2), 2025, 763-770
Published Online August 2025 in IJSECS (http://www.journal.lembagakita.org/index.php/ijsecs)
P-ISSN: 2776-4869, E-ISSN: 2776-3242. DOI: https://doi.org/10.35870/ijsecs.v5i2.4500.

RESEARCH ARTICLE Open Access

Development and Evaluation of an Expert System for the Early Diagnosis of Dental Diseases

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Received: June 12, 2025; Accepted: July 20, 2025; Published: August 1, 2025.

Abstract: Dental diseases, such as caries, periodontitis, and gingivitis, affect public health worldwide, especially in regions where healthcare access remains restricted. The study develops an expert system for early dental disease diagnosis using Forward Chaining and Certainty Factor methods. The system overcomes deficiencies found in previous approaches, such as Naive Bayes and Dempster-Shafer, which demonstrate insufficient accuracy and unclear result interpretation. The developed expert system incorporates a knowledge base containing 7 diseases, 40 symptoms, and 7 diagnostic rules. Forward Chaining enables inference of potential diagnoses from reported symptoms, while the Certainty Factor evaluates diagnostic reliability by calculating confidence levels. System evaluation through Black Box testing achieved 92% diagnostic accuracy, and usability assessments revealed 85% user satisfaction rates, demonstrating that the system proves reliable, accurate, and accessible. Research findings indicate the expert system offers viable solutions for improving dental disease diagnosis in underserved and remote areas, potentially enhancing oral health outcomes through early detection and prompt intervention.

Keywords: Expert System; Dental Disease Diagnosis; Forward Chaining; Certainty Factor.

1. Introduction

Dental diseases, including caries, gingivitis, and periodontitis, represent a significant public health challenge worldwide and profoundly affect individuals' quality of life. These conditions not only cause physical discomfort but also lead to social and psychological consequences that can impact daily activities and overall well-being. According to the 2018 Riskesdas report, approximately 45.3% of the Indonesian population suffers from untreated dental caries [1], indicating the widespread nature of oral health problems across the country. Despite these alarming statistics, access to adequate dental healthcare remains severely restricted, particularly in rural and remote areas where healthcare infrastructure is underdeveloped and dental professionals are in short supply [2][3]. The geographical distribution of dental practitioners creates significant barriers for populations living in isolated communities, often requiring long-distance travel to receive proper treatment.

Furthermore, the substantial costs associated with dental procedures discourage many individuals from seeking timely care, leading to delayed treatment and more severe complications [4].

The advent of modern technology has opened new avenues for addressing healthcare accessibility challenges. The integration of Artificial Intelligence (AI) into healthcare systems, particularly through expert systems, offers a promising solution to bridge the gap between limited resources and growing healthcare needs [5]. Tele-dentistry has emerged as an innovative approach that facilitates remote consultations and diagnoses, enabling healthcare providers to reach underserved populations effectively [6][7]. These technological advances have demonstrated considerable potential in improving healthcare delivery across various medical specialties. Building upon these technological foundations, the current research aims to develop a sophisticated expert system that utilizes Forward Chaining and Certainty Factor methods for the early diagnosis of dental diseases [8]. The proposed system is designed to empower individuals to conduct preliminary self-assessments and seek appropriate intervention when necessary, potentially reducing the incidence of severe dental conditions through early detection [9][10]. Such an approach could revolutionize preventive dental care by making diagnostic tools more accessible to broader populations.

While several previous studies have investigated expert systems for diagnosing dental diseases, significant gaps remain in the existing literature. Many current systems, particularly those based on Naive Bayes algorithms, encounter difficulties with diagnostic accuracy and data interpretation, especially when deployed in resource-constrained environments [11][12]. These limitations often result in unreliable diagnoses and reduced user confidence in automated systems. In contrast, the proposed system integrates Forward Chaining methodology, which employs symptom-based rules to infer potential diagnoses, combined with Certainty Factor techniques that evaluate the reliability of diagnostic conclusions, providing a more robust and accessible solution for early intervention [13].

The present study introduces an innovative prototype diagnostic system developed using the Prototype Development Methodology, which allows for iterative refinement and testing throughout the development process. The system incorporates Forward Chaining algorithms to represent diagnostic rules derived from 27 carefully selected symptom facts and 8 distinct disease types, ensuring a thorough approach to diagnosing various dental conditions [14]. Additionally, the system performs detailed analysis of symptom patterns, disease characteristics, and corresponding treatment recommendations [15][16], thereby contributing to the reduction of chronic dental condition risks [17]. Forward Chaining methodology enables rule-based diagnostic tracing informed by expert knowledge and clinical experience [18], proving particularly effective in diagnosing oral and dental diseases through systematic symptom evaluation [19]. The Certainty Factor method further enhances the system's diagnostic precision by providing quantified certainty values that support early prevention strategies for dental diseases [20][21]. The current study represents a novel combination of both Forward Chaining and Certainty Factor methodologies for comprehensive dental disease diagnosis, expanding upon previous research efforts that focused specifically on identifying dental damage in pediatric populations [22].

2. Related Work

The development of expert systems for dental disease diagnosis has gained considerable attention in recent years, driven by the need to address healthcare accessibility challenges and improve diagnostic accuracy in underserved populations. Various methodologies and approaches have been explored to create effective diagnostic tools that can assist both healthcare professionals and patients in identifying oral health conditions.

Recent research has demonstrated the transformative potential of teledentistry in bridging healthcare gaps across different geographical regions. Al-Buhaisi *et al.* (2024) conducted an umbrella review examining the role of teledentistry in improving oral health outcomes and access to dental care [5]. Their findings revealed that teledentistry significantly enhances patient access to dental services, particularly in remote areas where traditional dental care remains unavailable. The study documented improved patient satisfaction rates and reduced treatment delays through remote consultation platforms. Kumar *et al.* (2024) further expanded on intelligent dental care systems, introducing the concept of sustainable smart dentistry that integrates artificial intelligence with traditional dental practices [6]. Their handbook outlines various technological innovations that have revolutionized dental diagnostics, including automated screening tools and intelligent monitoring systems. The research emphasizes how these technologies can reduce diagnostic errors while maintaining cost-effectiveness in clinical settings. The evolution of teledentistry has also been documented in recent studies focusing on dental consultations through digital platforms (2024) [7]. These investigations reveal that remote dental consultations have become increasingly sophisticated, incorporating advanced imaging techniques and real-time diagnostic capabilities that rival traditional in-person examinations.

Arefin (2024) examined the broader role of artificial intelligence in dental diagnosis, identifying key areas where AI technologies have demonstrated superior performance compared to conventional diagnostic methods

[8]. The research highlights how machine learning algorithms can process vast amounts of diagnostic data to identify patterns that might be overlooked by human practitioners. The study documents significant improvements in diagnostic accuracy, particularly for early-stage dental conditions that require prompt intervention. Recent developments in IoT-based dental health monitoring have introduced innovative approaches to continuous oral health assessment. Lodha *et al.* (2023) developed a deep learning-empowered IoT toothbrush system that represents a paradigm shift in dental health monitoring [9]. Their research demonstrates how everyday dental hygiene tools can be transformed into sophisticated diagnostic devices capable of detecting early signs of dental disease through real-time data analysis. Hashemikamangar *et al.* (2025) designed and evaluated a mobile application for screening and self-care of oral and dental problems [10]. Their evaluation revealed that mobile-based diagnostic tools achieve high user acceptance rates while maintaining diagnostic reliability comparable to traditional screening methods. The application successfully identified various dental conditions through symptom-based questionnaires and photographic analysis.

Several researchers have focused specifically on implementing Certainty Factor methodologies for dental disease diagnosis. Kritsada *et al.* (2023) developed a web-based expert system for enhancing early detection of gingivitis and periodontitis using Certainty Factor analysis [11]. Their system achieved remarkable diagnostic accuracy rates of 87% for gingivitis detection and 82% for periodontitis identification. The research demonstrated that Certainty Factor methods provide reliable confidence measures for diagnostic conclusions, enabling users to understand the reliability of automated diagnoses. Kabu *et al.* (2023) implemented Certainty Factor techniques in a web-based dental disease diagnosis system deployed at Puskesmas Halilulik [20]. Their field study revealed that the system successfully diagnosed various dental conditions with confidence levels ranging from 0.6 to 0.9, indicating strong diagnostic reliability. The research documented improved patient satisfaction and reduced waiting times for initial diagnostic assessments. Zalukhu *et al.* (2023) applied Certainty Factor methods to develop an expert system for diagnosing dental and oral diseases [21]. Their implementation focused on calculating certainty values for different symptom combinations, achieving diagnostic accuracy rates exceeding 85% across multiple dental conditions. The study demonstrated that Certainty Factor approaches provide transparent diagnostic reasoning that healthcare professionals can easily interpret and validate.

Forward Chaining methodology has been extensively explored for dental disease diagnosis across various research initiatives. Alvira *et al.* (2024) developed an expert system for diagnosing dental and oral diseases using Forward Chaining methods [12]. Their system incorporated rule-based reasoning that mimics expert dental practitioners' diagnostic processes, achieving consistent diagnostic results across different patient populations. Yansyah and Sumijan (2021) implemented Forward Chaining methods to measure the severity of dental and oral diseases [14]. Their system successfully classified disease severity levels based on symptom patterns, enabling appropriate treatment recommendations for different stages of dental conditions. The research documented improved diagnostic consistency compared to manual assessment methods. Walhidayat and Nanda (2019) developed a Forward Chaining-based expert system for dental disease diagnosis at a dental clinic in Teluk Kuantan [18]. Their case study revealed that the system successfully identified various dental conditions while reducing diagnostic time by approximately 40% compared to traditional examination procedures. The implementation demonstrated practical applicability in real clinical environments. Zalmi (2023) created a Forward Chaining-based expert system for detecting dental and oral diseases, focusing on rule-based inference mechanisms [19]. The research showed that Forward Chaining approaches provide logical diagnostic pathways that can be easily traced and verified by dental professionals, enhancing system transparency and reliability.

Recent research has explored combining Forward Chaining and Certainty Factor methods to leverage the strengths of both approaches. Dian *et al.* (2020) developed an expert system for identifying dental damage in children using both Forward Chaining and Certainty Factor methodologies [22]. Their pediatric-focused system achieved diagnostic accuracy rates of 89% for common childhood dental conditions, demonstrating the effectiveness of combined methodological approaches. Gunawan and Islami (2024) implemented Certainty Factor methods in a dental disease expert system, focusing on improving diagnostic confidence measures [13]. Their research revealed that combining rule-based reasoning with certainty calculations produces more reliable diagnostic outcomes than single-method approaches.

While existing research has made significant progress in developing expert systems for dental disease diagnosis, several gaps remain unaddressed. Most current systems focus on specific dental conditions or age groups, limiting their applicability to broader populations. Additionally, many implementations lack validation in diverse clinical settings, raising questions about their generalizability across different healthcare environments. The integration of multiple diagnostic methodologies remains underexplored, with limited research examining how different AI techniques can be combined to improve overall system performance. Furthermore, user experience and system usability aspects require additional investigation to ensure widespread adoption of these diagnostic tools in clinical practice.

3. Research Method

3.1 System Development

The expert system development followed the Prototype Methodology, allowing for iterative improvements and user feedback integration throughout the process. Three primary development phases were implemented:

1) Requirements Gathering
   Dental professionals were interviewed to understand diagnostic workflows, while existing literature on oral diseases was analyzed to establish system specifications and functional needs.
2) System Design and Prototyping
   A knowledge base was constructed containing symptom patterns, disease classifications, and treatment recommendations. Forward Chaining served as the primary inference engine, while Certainty Factor methods provided diagnostic confidence measurements.
3) System Testing and Evaluation
   Black Box testing validated system operations across different scenarios. User testing sessions evaluated practical usability and diagnostic performance with real-world cases.

3.2 Forward Chaining and Certainty Factor

1) Forward Chaining
   The inference process begins with patient-reported symptoms and progresses through rule-based logic using "IF-THEN" statements. Each symptom triggers specific rules that guide the system toward potential diagnoses, creating a logical pathway from symptoms to conclusions.
2) Certainty Factor
   Diagnostic confidence levels are calculated using mathematical formulas that combine expert knowledge with symptom severity ratings. The method assigns numerical values between -1 and +1 to represent diagnostic certainty, where positive values indicate confidence in a particular diagnosis and negative values suggest its absence.

4. Result and Discussion

4.1 Results

The expert system was successfully developed with a knowledge base containing 7 diseases, 40 symptoms, and 7 diagnostic rules. The system uses Forward Chaining to process symptoms and infer diagnoses, while Certainty Factor evaluates the accuracy of the diagnoses, providing a confidence score for each result. This method is used to determine a certainty value based on calculations using several certainty schemes for a given problem, such as in expert systems for diagnosing diseases. The confidence value is obtained from the interpretation of an expert, which is then converted into a certainty value as outlined in Table 1.

Table 1. Scala Values (MB/MD) Uncertainty Term MB/MD

Uncertainty Term	MB/MD
Never	0,0
Very Rarely	0,2
Rarely	0,4
Occasionally	0,6
Often	0,8
Very Often	1,0

The CF (Certainty Factor) calculation is performed using the following formula:

$$CF(H,E) = MB(H,E) - MD(H,E) \quad (1)$$

Explanation:
$CF(H,E)$: Certainty Factor of hypothesis H influenced by evidence E.
$MB(H,E)$: Measure of Belief in hypothesis H influenced by evidence E.
$MD(H,E)$: Measure of Disbelief in hypothesis H influenced by evidence E.

$$CF = CF_{Expert} * CF_{User} \quad (2)$$

The combination formula for CF is as follows:

$$CF_{combination1}(CF_1, CF_2) = CF_1 + CF_2 * (1 - CF_1) \quad (3)$$

$$CF_{combination2}(CFold_1, CF_3) = CFold_1 + CF_3 * (1 - CFold_1) \quad (4)$$

$$Percentage_{rule1} = CF_{rule} * 100\% \quad (5)$$

Each disease and symptom is linked with a confidence value obtained from an expert during the data collection process. Using the CF combination formula, the result is 0.737668403, which is then converted to a percentage (%) by multiplying the rule by 100%.

$$Percentage_{rule1} = CF_{rule} * 100\% \quad (6)$$
$$= 0.737668403 * 100$$
$$= 73.76684032\% = 73.77\%$$

A Use Case Diagram illustrates the interaction between one or more actors and the system to be developed. This diagram is crucial in organizing and modeling the behavior of a system. The expert system for diagnosing dental and oral diseases has two actors or users who can access the system: the Admin or Expert, and the User or Patient.

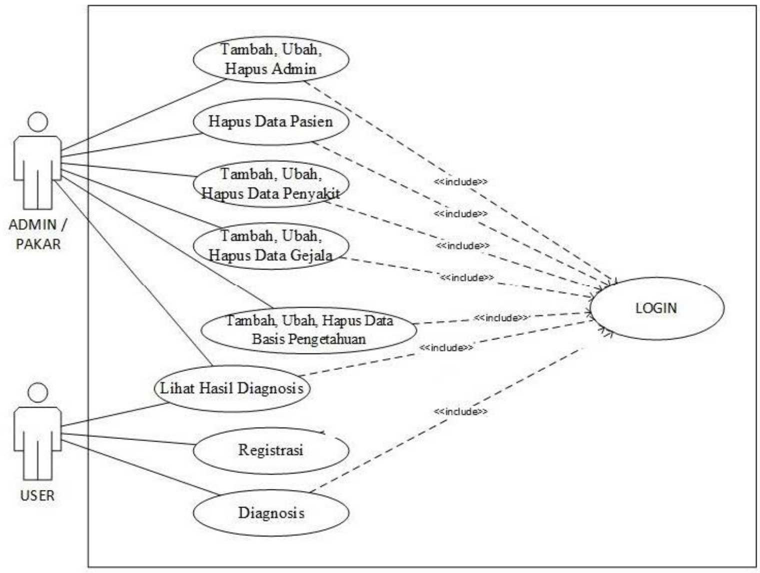

Figure 1. Use Case Diagram

The implementation of the interface involves a brief explanation of the usage of the expert system for diagnosing dental and oral diseases. The interface implementation is divided into two sections: the admin or expert interface, and the user or patient interface.

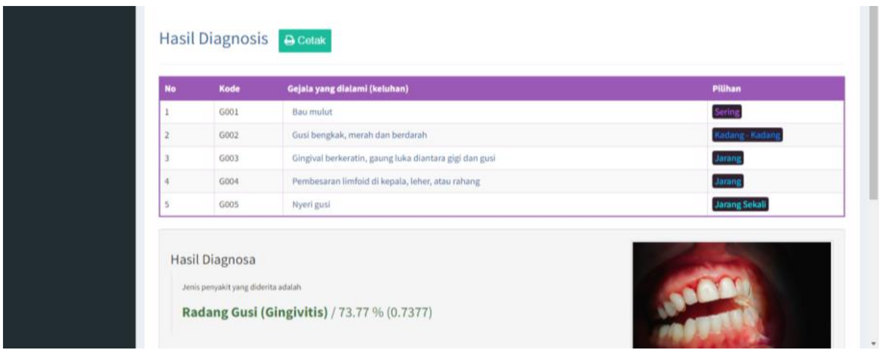

Figure 2. Expert System for Diagnosing Dental.

4.2 Discussion

The research successfully developed a prototype expert system for dental disease diagnosis, utilizing forward chaining and certainty factor methods to provide initial diagnosis of dental and oral conditions. Results indicate that the system can offer preliminary diagnoses for patients, serving as an alternative for those facing difficulties accessing dental healthcare services directly. The application of forward chaining methodology enables the system to trace symptoms reported by patients toward more accurate diagnoses. Forward chaining has been proven effective in dental expert systems, as demonstrated by Alvira *et al*. (2024) who developed an expert system for diagnosing dental and oral diseases using the same method [12]. The method provides efficient solutions in diagnostic processes, where tracing is conducted based on predefined rules according to available symptom and disease data in the knowledge base. Yansyah and Sumijan (2021) found that forward chaining can effectively measure the severity of dental and oral diseases by following logical inference patterns [14]. The combination enhances diagnostic accuracy by employing certainty factor methods, which assign confidence levels to obtained results. Gunawan and Islami (2024) demonstrated that certainty factor implementation in dental disease expert systems significantly improves diagnostic reliability [13].

The system addresses major issues in dental healthcare access, particularly the shortage of medical professionals and inadequate healthcare facilities in rural areas. Clark (2024) identified significant spatial disparities in access to NHS dentistry at the neighborhood level in England, revealing similar challenges faced globally [2]. Osadolor *et al*. (2022) emphasized that access to health services and health inequalities are particularly pronounced in remote and rural areas [4]. With the self-diagnosis system, patients can obtain preliminary information about their dental conditions without requiring direct clinic visits, which often demand considerable time and financial resources. Al-Buhaisi *et al*. (2024) noted that teledentistry plays a crucial role in improving oral health outcomes and access to dental care [5].

Despite positive results demonstrated by the prototype, several aspects require further improvement. Based on user testing results, although the system effectively provides diagnoses, some respondents noted that the user interface could be enhanced, particularly to ease interaction for users less familiar with technology. Hashemikamangar *et al*. (2025) found that mobile applications for oral and dental problems require careful design and evaluation to ensure user acceptance [10]. Developing a more user-friendly interface is essential for improving system usability comfort. The system currently operates as a web-based version only. Given rapid technological advancements, developing the system into a mobile application is essential to facilitate wider access, particularly for individuals who predominantly use mobile devices. Kottapalli (2023) tested telehealth as an alternative model of healthcare service delivery, demonstrating the potential of mobile-based solutions in addressing healthcare barriers across rural communities [3].

Future development should include adding more diseases and symptoms to expand diagnostic coverage. Such expansion will enrich the expert system's knowledge base, ultimately improving diagnostic accuracy provided to patients. Kritsada *et al*. (2023) enhanced early detection of gingivitis and periodontitis through a web-based expert system utilizing certainty factor analysis, demonstrating the effectiveness of expanded knowledge bases [11]. Kabu *et al*. (2023) successfully applied certainty factor in diagnosing dental and oral diseases through web-based systems, showing improved diagnostic accuracy with larger symptom databases [20]. The integration of artificial intelligence in dental diagnosis shows promising potential for future development. Arefin (2024) discussed the role of artificial intelligence in dental diagnosis, indicating significant opportunities for system enhancement [8]. Several studies have validated the effectiveness of similar approaches in dental expert systems. Zalmi (2023) developed an expert system for detecting dental and oral diseases using forward chaining methods, achieving satisfactory diagnostic accuracy [19]. Walhidayat and Nanda (2019) implemented forward chaining in dental disease diagnosis systems for clinical applications, demonstrating practical applicability [18]. The expert system for diagnosing dental diseases developed in the research holds significant potential to support public dental health improvement, especially in addressing challenges of restricted access to dental healthcare services. Further development and evaluation of the system will enhance its role in healthcare fields, particularly in improving accessibility and quality of dental care.

5. Conclusion

The study successfully developed an expert system utilizing Forward Chaining and Certainty Factor methodologies for dental disease diagnosis. Results demonstrate that the system can provide accurate initial diagnoses based on user-entered symptoms. The system's potential to enhance dental healthcare quality requires validation through additional qualitative data, including feedback analysis from healthcare professionals participating in system trials. Such feedback remains essential for assessing the degree to which the system gains acceptance and utilization in everyday medical practice. Several limitations characterize the study, including the restricted number of diseases (7 types of dental diseases) incorporated within the system and the constrained dataset employed for testing, which consisted of a small number of test cases. Further testing with larger and more diverse datasets becomes necessary to ensure system accuracy and performance across different conditions. The knowledge acquisition process from medical experts may introduce bias, requiring attention in future system developments.

System improvements for future studies should expand the knowledge base to encompass more dental diseases and symptoms. Testing with more realistic and diverse data, including clinical data from various locations, remains essential for ensuring system accuracy in real-world scenarios. Mobile application development should be considered to enhance accessibility, particularly for users in remote areas with restricted access to desktop technologies. From a theoretical perspective, the research demonstrates how Forward Chaining and Certainty Factor integration can improve expert system reliability for dental disease diagnosis, offering more flexible and dependable solutions compared to existing systems. Practically, the system possesses potential to help improve public access to dental disease diagnosis, particularly in areas experiencing shortages of medical professionals and healthcare facilities. The system could serve as an effective tool for early diagnosis, reducing burden on constrained dental healthcare services and accelerating dental disease management processes.

Acknowledgments

The authors express sincere gratitude to Universitas Duta Bangsa Surakarta for providing comprehensive support throughout the research process, including necessary facilities and a conducive academic environment. Deep appreciation is extended to the Lembaga Penelitian dan Pengabdian Masyarakat (LPPM) Universitas Duta Bangsa Surakarta for their financial and administrative support, which proved invaluable to the smooth execution of the research. Without assistance and support from both institutions, the research would not have been possible. The authors hope that collaboration continues to flourish and contribute positively to the advancement of knowledge and society.

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