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A WEARABLE SELF-LEARNING EXPERT SYSTEM FOR DENTAL TRAUMA DIAGNOSIS PROCESS

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Abstract. This study proposes a novel intelligent system for the diagnosis of dental trauma. The system utilizes the International Dental Trauma Association's (IADT) established guidelines as its knowledge base and employs a data-driven, forward-chaining inference engine to identify the specific injury type. Following diagnosis, dentists can leverage the system to generate comprehensive reports detailing the entire diagnostic process and meticulously plan subsequent treatment procedures. Additionally, the system facilitates the secure storage of patient data, enabling potential integration with existing hospital information systems. Designed for deployment on both smart glasses and mobile devices, this application empowers dental professionals with a readily accessible, wearable diagnostic tool grounded in the latest IADT recommendations. The system leverages forward-chaining reasoning to diagnose a broad spectrum of dental trauma cases, encompassing both uncomplicated and complex presentations. Furthermore, it generates reports that not only outline the diagnostic conclusion but also transparently document the decision-making process alongside relevant patient information. This innovative application offers significant enhancements to the conventional diagnostic workflow by facilitating uninterrupted eye contact with the patient during examinations. As a result, it is anticipated to provide valuable support to specialists, general dentists, and even dental students in effectively managing the diagnosis, treatment planning, and follow-up of dental trauma cases.

Keywords. Expert systems, neural networks, dental trauma, wearable devices.

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1. INTRODUCTION

International Association of Dental Traumatology (IADT) has generated a set of detailed guidelines for managing the diagnosis process [1]. The guidelines specified in that gold standard were structured in form of a decision tree that can be followed by the dentists to decide on a particular trauma type. Following treatment, follow-up procedures and methods were also provided in the guidelines in order to deal with any complications that are likely to occur. It is extremely important to use such a guideline for the standardization of the diagnostic and treatment procedures. The structure of the guideline naturally allows modelling it using expert systems. This also provides an opportunity to make more adaptive to new trauma cases when neural networks are employed.

Expert systems provide a number of advantages over human experts. The primary advantage is consistency which might be described because the ability to come back up with the identical answers when the identical questions are provided. Memory is another advantage since computer systems are capable of storing and processing large amounts of information. Finally, the decision-making process in expert systems is logical and objective, purely supported rules defined on the system [2]. These properties of expert systems make them attractive in challenging decision-making processes such the diagnosis of dental traumas.

This manuscript presents a novel expert system application for dental trauma diagnosis. The application leverages a curated knowledge base, comprised of the aforementioned rules, and prioritizes seamless integration with mobile and wearable computing devices, such as smart glasses. This strategic integration ensures accessibility during the diagnostic evaluation process, minimizing disruption to the dentist-patient interaction. The system employs a forward-chaining inference engine to arrive at conclusions that closely adhere to the established International Association of Dental Traumatology (IADT) guidelines. Notably, the application incorporates the entirety of the IADT guideline tree, enabling dentists to make informed selections of pertinent clinical and radiological findings through user-friendly menus. It is paramount to emphasize that this application is not intended to supplant established clinical judgment. Instead, it functions as a complementary resource, facilitating the application of IADT guidelines in a more user-centric manner compared to conventional paper-based references. This enhanced user-friendliness capitalizes on the ubiquitous nature of mobile devices in contemporary society, potentially promoting greater adoption of such software tools among dental professionals. Furthermore, the system's ability to process symptom data and generate differential diagnoses substantiates its value as a valuable diagnostic aid.

2. Literature Review and Background

Dental trauma represents a significant public health concern, with tooth injuries prevailing over soft tissue injuries in the oral cavity [3]. This ubiquity presents a global challenge for clinicians, often resulting in emergency situations that inflict pain and distress on both children and their caregivers [4, 5]. Studies highlight a substantial proportion of dental trauma cases presenting at hospital emergency departments. Moreover, dental injuries pose a serious threat to children's overall health, impacting them physically, aesthetically, and psychologically. Early childhood trauma can disrupt the development and eruption of permanent teeth. The treatment of dental trauma can be complex, with accurate diagnosis and timely intervention posing significant challenges [6].

The diagnosis and treatment of dental trauma in young children are often hindered by their lack of cooperation and fear [7]. This underscores the critical need for rapid and accurate diagnosis, particularly in cases where early intervention is crucial. Diagnostic goggles designed for this purpose hold significant promise in facilitating the timely application of optimal treatment for pediatric patients with dental trauma. Dental trauma cases often necessitate collaboration among a diverse range of dental professionals, including oral and maxillofacial surgeons, pediatric dentists, endodontists, orthodontists, prosthodontists, and periodontists. Initial emergency care is typically provided by oral and maxillofacial surgeons, pediatric dentists, or general dentists in hospital emergency departments. Given the multidisciplinary nature of dental trauma treatment, readily accessible, up-to-date knowledge becomes critical for successful intervention [8]. Management of dental trauma in children presents a particular challenge within dental practice settings. Effective management hinges on familiarity with current trauma guidelines to ensure optimal outcomes. Ideally, a treatment guide for pediatric dental injuries should empower dentists and other healthcare providers by offering reliable, user-friendly, and practical guidance, ultimately facilitating optimal and efficient patient care [9].

This diagnostic tool, built upon the established 2012 guidelines from the International Association of Dental Traumatology (IADT), is designed to support clinicians throughout the diagnosis, treatment, and follow-up stages of dental trauma management.

Expert systems capture and encode the knowledge of human experts within a computer program, enabling autonomous task execution. Empirical learning methods, on the other hand, rely on training examples without explicit domain knowledge. However, these methods can lack interpretability as they don't explain why data belongs to a specific class. Combining these approaches can offer advantages. Hybrid systems, such as Knowledge-Based Artificial Neural Networks (KBANNs), integrate hand-crafted rules with neural networks trained on classified samples [10, 11]. This combination leverages the strengths of both paradigms: symbolic learning provides domain-specific knowledge for improved accuracy, while neural networks excel at handling complex patterns and generalizing to unseen data.

Knowledge-Based Artificial Neural Networks (KBANNs) integrate symbolic knowledge, in the form of domain-specific rules, with the learning capabilities of artificial neural networks (ANNs). This hybrid approach offers advantages: KBANNs leverage expert knowledge to encode rules into the ANN, potentially improving its accuracy. However, a limitation of KBANNs lies in the potential for incomplete or inaccurate knowledge bases, which can negatively impact performance. Additionally, while KBANNs excel at generating new ANNs and tackling complex problems in various domains [12]. Often, it's difficult to understand the reasoning behind an ANN's decision, which can limit trust in its real-world applications.

The term "wearable" is frequently paired with technology ("wearable technology") or devices ("wearable devices") to denote electronic devices comfortably incorporated into clothing or accessories. Smart glasses, exemplified by Google Glass, Epson Moverio, Vuzix M100, and Optivent Ora, represent a prominent category within the burgeoning wearable technology market [13]. These devices typically incorporate a camera, display, speaker, and Wi-Fi connectivity, although variations exist in price, control method, display resolution, and field of view (FoV). Within the healthcare domain, wearable technology has garnered significant research interest for applications such as health monitoring, surgical procedures, remote patient monitoring, access to health data, and medical education [14]. This following delves into the details of the developed system, covering its architecture, expert system integration, data persistence mechanisms, and user interface design as an improvement of the system developed in [15].

3. Material and Methods

This study centers on developing a mobile application to empower dentists in diagnosing and treating dental trauma, ultimately aiming to minimize patient suffering due to misdiagnosis. The application, designed for Android devices (tablets, smartphones, and smart glasses), offers functionalities for dentist user management (registration, record modification/deletion) encompassing both patient demographics and medical history. Patient symptom data is transmitted to a server for diagnosis. Upon determination of the dental condition by the server, the dentist's device receives the results. Subsequently, an automated report is generated based on the diagnosis, with the option to convert it to a PDF format.

The system adheres to a client-server architecture. The server awaits and responds to dentist-initiated requests from their client devices (tablets, smartphones, smart glasses). The server-side houses the expert system's inference mechanism, employing a forward-chaining approach to diagnose dental trauma based on patient symptoms received from the client. This data-driven inference method progressively applies rules from the knowledge base to arrive at a conclusion. Node.js with the Express module facilitates server-side development, while the node-rules module streamlines rule generation and forward-chaining implementation.

While designed for dental trauma diagnosis, the system's core inference mechanism exhibits potential for broader applicability in areas like oral pathology diagnosis. To illustrate its functionality, consider the following scenario: a permanent tooth exhibits mobility, displacement, and movement alongside adjacent teeth and alveolar bone. The inference engine employs a forward-chaining approach, iteratively evaluating the antecedent conditions (IF clauses) of the rules in the knowledge base. Matching rules are then executed in a specific order, as the results of one iteration influence the inputs of the next. This process continues until all available information is exhausted, culminating in a diagnosis. Notably, the IADT-based knowledge base employed here avoids potential conflicts arising from rule antecedents with competing consequences, as the system utilizes distinct symptom paths for inference.

Upon receiving patient symptoms from the client device, the server leverages its knowledge base to perform a rule-based comparison (inference). If a diagnosis is reached, the server retrieves comprehensive information from a MySQL database encompassing the trauma type, treatment options, follow-up procedures, and potential positive or negative outcomes. This retrieved information is then transmitted back to the dentist's device in JSON format via HTTP POST requests.

The system incorporates two distinct databases. The first, stored locally on each device using SQLite, serves as a personal database for dentists. It securely stores patient information and their respective reports. The second database, residing on the server, houses the expert system's knowledge base. This separation is essential as the rule base and inference mechanism can require significant memory resources, rendering client-side processing inefficient. A two-tier architecture effectively addresses this challenge. Figure 1 illustrates the system's overall architecture. In our architecture, the server side is responsible for the execution of the expert system. The knowledge base is also stored here and the forward chaining process is executed in the server. The results are then sent to the dentist for aiding the decision making process.

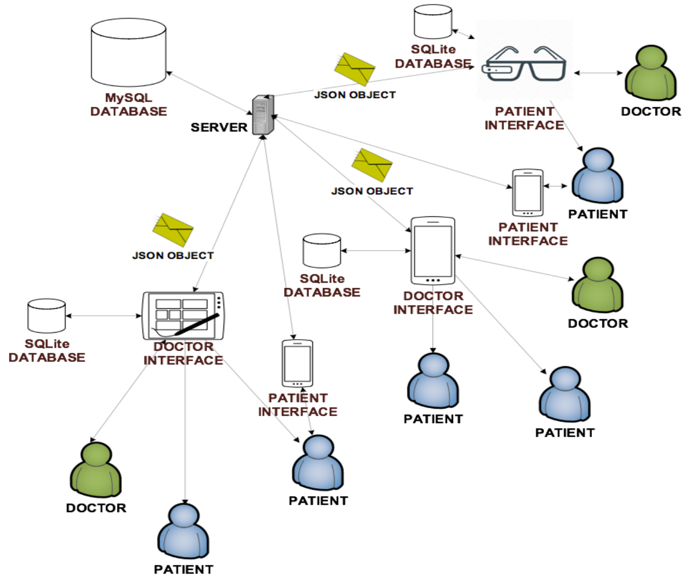

FIGURE 1. System architecture.

4. RESULTS

This section delves into the analysis of the developed system. A key feature of the expert system-based application is the symptom path diagram. This visual aid illustrates the decision-making process, guiding users through the sequence of choices that lead to a specific diagnosis. A sample flow is given in Figure 2.

Furthermore, the system leverages a Multi-Layer Perceptron algorithm to achieve a high degree of accuracy in dental trauma classification. As shown in Table 1, this algorithm achieved an impressive 87.5% correct classification rate using a sample set generated based on the IADT guidelines. This performance metric underscores the potential for the knowledge base to be refined and enhanced over time. For a more comprehensive analysis of the tested algorithms' performance across various folds, please refer to Figure 3.

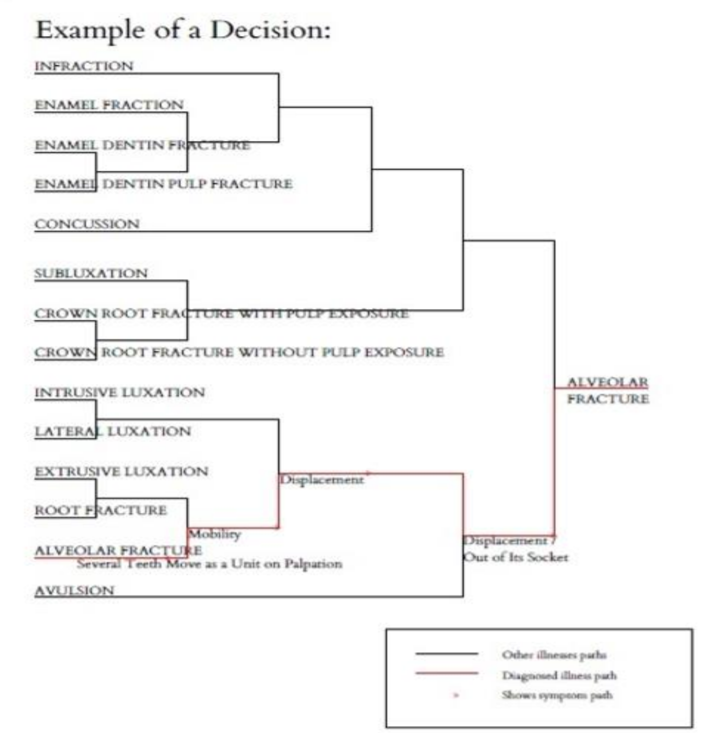

FIGURE 2. Sample decision path.

TABLE 1. Performance evaluation of the learning algorithms used.

Criterion	Multilayer Perceptron	KStar	K-nearest neighbours	Sequential Minimal Optimization	Simple Logistic Regression
Accuracy	%87.5	%78.125	%71.875	%71.875	%87.5
RMSE	0.1241	0.162	0.1728	0.2456	0.117
Kappa Statistic	0.8647	0.7637	0.6959	0.6959	0.8648

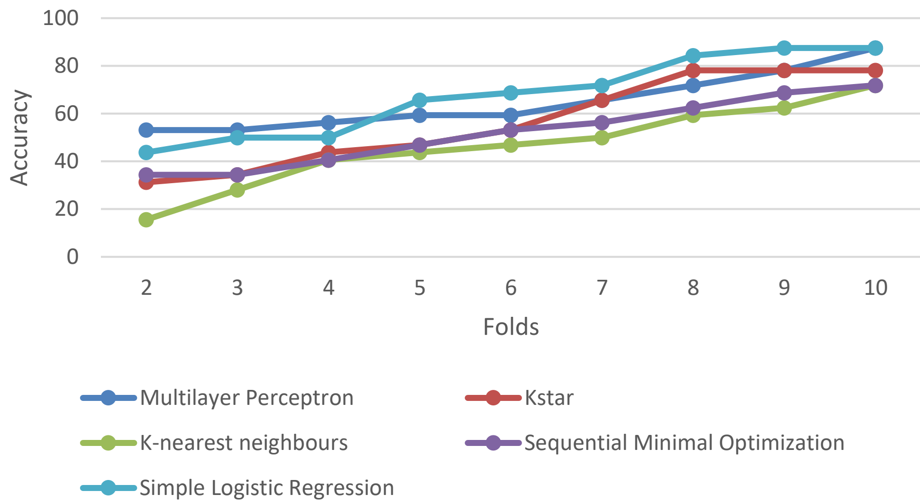

FIGURE 3. Algorithm performances over folds tested.

The new rules were very similar to the IADT rules. For instance, in the IADT rules, the symptoms necessary to achieve the diagnosis of extrusive luxation are:

- Type => Permanent Tooth
- Mobility => Mobility
- Mobility => Single Tooth
- Clinical Findings => Displacement
- Radiographic Findings => Increased Periodontal Ligament Space Apically

In the created rule, the symptoms are as follows;

- Radiographic Findings => Increased Periodontal Ligament Space Apically
- Mobility => Single Tooth
- !(Response to Pulpal Test => Positive) [1]
- Clinical Findings => Displacement

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[1] Exclamation mark shows that the absence of these symptoms is necessary.

- !(Clinical Findings => No Displacement)
- !(Response to Pulpal Test => Negative)
- !(Radiographic Findings => Apical Extension of Fracture Usually Not Visible)
- !(Percussion Test => Tenderness to Percussion)
- !(Radiographic Findings => Fracture Lines Located at Any Level, from The Marginal Bone to The Root Apex)
- !(Percussion Test => No Tenderness to Percussion)
- !(Radiographic Findings => X-Ray Signs of Root Fracture)
- !(Clinical Findings => Incomplete Fracture)
- !(Clinical Findings => Bleeding from Gingival Crevice)

Although the new rule has different symptoms than the original, it does not indicate that the newly created rule is false. This result proves that the system can learn. A medical report can be converted to PDF file format and sent to the dentist's device. The report contains information about patient’s name, SSN as well as the details of the diagnosis and treatment including date, diagnosis, symptom path, treatment, favorable outcomes, unfavorable outcomes and follow up. In general, personal information and report information exceeds one page. In these situations, the system adds new page to the PDF automatically. Page overflow problem is solved automatically. Computed Tomography (CT) and radiographic images are also important parts of the diagnosis process and can be incorporated into the report to be saved for follow ups, treatment of possible complications and archival purposes.

5. Conclusion and Future Directions

This study presented a novel wearable diagnostic system designed to assist clinicians in diagnosing traumatic dental injuries. While traditional diagnosis relies heavily on clinician expertise and examinations, this system offers supplementary support by leveraging the gold standard Andreasen classification system. By incorporating this classification, the system facilitates user correlation between the diagnosis and established IADT treatment guidelines, ultimately aiding in treatment planning and prognosis prediction.

The proliferation of mobile health applications can pose challenges for users in discerning reliable solutions. This system distinguishes itself through its emphasis on usability and a focus on database creation.

Furthermore, the system recognizes the critical role of follow-up care in successful outcomes. Drawing from IADT guidelines, it generates dentist follow-up alerts via email, ensuring adherence to evidence-based practices. Beyond supporting experienced dentists, this system also holds promise for students and clinicians in early practice stages, as well as emergency situations lacking access to specialists.

Future research should evaluate the system's impact on diagnostic accuracy across various healthcare providers, including private practitioners, dentists, and undergraduate students. Additionally, exploring voice command integration with smart glasses in future system iterations could further enhance user experience and efficiency.

Author Contribution Statements GBS conceived the study and prepared the manuscript, GEB developed the system and performed experiments and revised the manuscript.

Declaration of Competing Interests The authors declare no competing interests.

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