



Diphtheria Diagnosis Expert System: Leveraging Fuzzy Logic for Precision and Efficiency in Infectious Disease Detection

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ABSTRACT

This research introduces the Diphtheria Diagnosis Expert System (DDES), a pioneering computational tool employing fuzzy logic for the accurate and rapid identification of diphtheria cases. The study builds upon previous research, addressing the limitations of conventional diagnostic methods in recognizing the diverse and evolving presentations of diphtheria. Through meticulous data acquisition from diverse sources, including medical records, public health databases, and historical case studies, a comprehensive dataset was curated, laying the foundation for the DDES's development. The DDES's utilization of fuzzy logic, a dynamic computational framework, empowers it to navigate the intricacies of diphtheria symptomatology. This study demonstrates the system's enhanced diagnostic accuracy, adaptability to varied clinical presentations, and efficiency in delivering rapid outcomes. Comparative analyses with previous research highlight the DDES's advancements, showcasing superior diagnostic precision and speed. Its potential impact on resource optimization within healthcare systems, ethical considerations, and seamless integration into clinical practice are significant contributions to the broader field of infectious disease diagnosis. The expert system's practical utility is emphasized through positive user feedback, indicating its potential acceptance among healthcare professionals. Ethical considerations, including privacy and transparency, are meticulously addressed, aligning the DDES with the highest standards of responsible technological deployment.

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1. INTRODUCTION

Diphtheria, a bacterial infection caused by *Corynebacterium diphtheriae*, has been a persistent threat to public health throughout history (Mattos-Guaraldi et al., 2003). This bacterium primarily infects the respiratory tract, leading to a range of symptoms and potential complications. Understanding the causes, symptoms, and complications of diphtheria is crucial for effective disease management and underscores the importance of advancements in diagnostic methodologies (Kilgore et al., 2016).

Corynebacterium diphtheriae, the causative agent of diphtheria, is a gram-positive, rod-shaped bacterium (Weiss & Efstratiou, 2013). It produces a potent exotoxin that is a key factor in the pathogenesis of the disease. Transmission occurs through respiratory droplets from infected individuals or carriers. Diphtheria is highly contagious, and susceptible individuals can contract the infection through close contact with respiratory secretions or fomites (Doley et al., 2016).

The clinical manifestations of diphtheria can vary, with symptoms typically appearing 2 to 5 days after exposure (Truelove et al., 2020). The hallmark feature is the development of a thick, grayish-white membrane in the throat or nose, which can lead to airway obstruction. Common symptoms include sore throat, difficulty swallowing, and a low-grade fever. Systemic effects may include weakness, malaise, and swollen lymph nodes. In severe cases, the exotoxin can spread through the bloodstream, causing damage to organs such as the heart and nervous system (Paul, 2024).

Diphtheria can lead to a spectrum of complications, ranging from mild to severe (Prasad & Rai, 2018). One of the immediate threats is airway obstruction due to the formation of the characteristic membrane in the throat. This can result in respiratory distress and, if left untreated, may lead to respiratory failure. The exotoxin produced by *C. diphtheriae* can also cause myocarditis, leading to cardiac complications such as arrhythmias and heart failure (Samdani et al., 2018).

Furthermore, the nervous system may be affected, resulting in paralysis (Todd, 1856). This complication, known as diphtheritic polyneuropathy, typically occurs a few weeks after the onset of the infection. Neurological involvement can lead to difficulties in breathing and swallowing, as well as limb weakness (Mehanna & Jankovic, 2010).

Diphtheria, a bacterial infection caused by *Corynebacterium diphtheriae*, necessitates prompt and accurate diagnosis for effective clinical management and prevention of complications (N. C. Sharma et al., 2019). Current diagnostic methods, while established, are not without limitations.

One of the traditional methods for diagnosing diphtheria involves evaluating clinical symptoms and isolating the bacteria through microbiological culture (N. C. Sharma et al., 2019). However, this method relies on the visible presence of the characteristic membrane in the throat and may not be definitive in mild or atypical cases. Additionally, culture-based approaches are time-consuming, often taking several days, which delays the initiation of targeted interventions (Watkins et al., 2022).

Molecular techniques, such as PCR, offer a more sensitive and rapid means of detecting *C. diphtheriae* DNA (Berger et al., 2014). PCR allows for the specific identification of the bacterium, even in the absence of visible symptoms. Nevertheless, PCR requires specialized laboratory equipment and trained personnel, limiting its accessibility in resource-limited settings where diphtheria outbreaks may be more prevalent (SCHEMES, 2019).

Serological tests, which detect antibodies against the diphtheria toxin, can aid in confirming the diagnosis (Walory et al., 2000). However, these tests may not be practical in the acute phase of the infection, as antibody levels take time to rise. Moreover, they are less useful for confirming diphtheria in vaccinated individuals, as the presence of antibodies can result from prior immunization.

Relying solely on clinical symptoms for diagnosis presents challenges due to the variable and sometimes nonspecific nature of diphtheria symptoms. Other respiratory infections can manifest similarly, leading to misdiagnosis or delayed treatment. The lack of distinctive features in the early stages of the disease can contribute to the rapid spread of diphtheria within communities.

Moreover, rapid diagnosis plays a crucial role in implementing effective public health measures, such as isolation and vaccination of contacts, which are vital for preventing further transmission (A. Sharma et al., 2021). The development of an expert system using fuzzy logic holds promise in enhancing the diagnostic accuracy by considering the inherent uncertainties in clinical data, thus contributing to the timely identification and containment of diphtheria cases (Nazayer, 2022).

In this context, the integration of fuzzy logic into an expert system presents a promising solution (Bose, 1994). Fuzzy logic, a mathematical framework that deals with uncertainty and imprecision, is particularly suited for medical diagnoses where symptoms and clinical manifestations may not always exhibit clear-cut boundaries (Seising, 2006).

Existing diagnostic methodologies for diphtheria often rely on rigid decision boundaries, which may lead to false negatives or delayed diagnoses. Fuzzy logic, by contrast, allows for a more flexible and nuanced approach, capturing the inherent uncertainties in clinical data. This research seeks to harness the power of fuzzy logic to develop a Diphtheria Diagnosis Expert System (DDES) that not

only streamlines the diagnostic process but also accommodates the inherent complexity and variability associated with the disease (Davey, 2011).

Several challenges in the current diagnostic landscape motivate the exploration of an expert system based on fuzzy logic (Jao, 2010). Firstly, the symptoms of diphtheria can mimic those of other respiratory infections, leading to misdiagnosis or delayed treatment. Secondly, the rapid identification of potential diphtheria cases is crucial for implementing timely interventions and preventing the spread of the disease. Lastly, the evolving nature of infectious diseases necessitates adaptive diagnostic systems capable of learning from new data and refining their diagnostic capabilities over time.

By combining the precision of medical expertise with the flexibility of fuzzy logic, the proposed DDES aims to enhance the accuracy of diphtheria diagnosis (Pavlou & Turner, 2000). The system is designed to analyze clinical data, considering the uncertainty inherent in medical information, and provide clinicians with timely and reliable diagnostic recommendations. In doing so, this research not only addresses current limitations in diphtheria diagnosis but also contributes to the broader discourse on the application of computational intelligence in improving healthcare outcomes.

In the subsequent sections of this research, we delve into the methodology employed for developing the DDES, the architecture of the expert system, and the results obtained through rigorous testing (Clark et al., 2003). Through this exploration, we aim to demonstrate the potential of fuzzy logic-based expert systems in transforming the landscape of infectious disease diagnosis, with a focus on the specific challenges posed by diphtheria (McLaughlin, 2019).

2. RESEARCH METHOD

The methodology employed in this research aimed to design and implement a Diphtheria Diagnosis Expert System (DDES) utilizing fuzzy logic as the underlying computational framework. The process involved several key steps, encompassing the collection of relevant data, the development of the expert system architecture, and rigorous testing to evaluate its performance.

The first step involved defining the fuzzy logic model, wherein linguistic variables and membership functions were carefully selected and tailored to the clinical parameters relevant to diphtheria diagnosis. Symptoms such as sore throat, difficulty swallowing, and fever were quantified linguistically, allowing for the representation of their degrees of severity. Membership functions characterized the fuzzy sets, facilitating the translation of qualitative clinical information into quantitative fuzzy values.

A pivotal aspect of the methodology was the construction of a rule-based system that encoded the expertise of healthcare professionals in diagnosing diphtheria. Fuzzy rules were established, connecting the linguistic variables to diagnostic outcomes. These rules incorporated the intricate relationships between symptoms, ensuring that the system could capture the subtle nuances and uncertainties inherent in clinical presentations of diphtheria. Medical expertise and existing diagnostic guidelines informed the formulation of these rules, providing a robust foundation for the fuzzy inference engine.

The fuzzy inference engine served as the computational core of the expert system. It utilized the defined membership functions and fuzzy rules to process input data and generate fuzzy outputs. The engine employed methods such as Mamdani or Sugeno to aggregate fuzzy information and derive diagnostic conclusions. The adaptability of fuzzy logic allowed the system to consider the overlapping and fuzzy nature of symptoms, enabling a more realistic representation of the diagnostic process compared to traditional binary logic systems.

To enhance the compatibility of the expert system with real-world clinical data, a data preprocessing module was integrated. This module standardized and normalized input data, ensuring consistency and optimizing the system's ability to interpret diverse datasets. Fuzzy logic variables were then assigned to the preprocessed data, aligning the information with the linguistic variables defined in the fuzzy logic model.

Recognizing the importance of providing clear and interpretable diagnostic outputs, a post-processing module was incorporated. This module translated the fuzzy outputs into well-defined diagnostic categories, enhancing the system's interpretability for healthcare professionals. The post-

processing step allowed for seamless integration of the fuzzy logic-based assessments into the clinical decision-making process.

The developed expert system underwent a training phase using a subset of the collected dataset. During training, the fuzzy logic model adapted its parameters to the intricacies of the data, optimizing its diagnostic performance. The training process aimed to enhance the system's ability to discern patterns and relationships within the clinical data, improving its diagnostic accuracy.

Rigorous validation and testing phases followed, utilizing distinct datasets to assess the generalization capabilities and robustness of the DDES. Performance metrics, including sensitivity, specificity, and accuracy, were employed to evaluate the system's diagnostic efficacy. Testing involved simulating real-world clinical scenarios and comparing the system's outcomes with established diagnostic methods to assess its potential advantages.

3. RESULTS AND DISCUSSIONS

3.1 Results of the Diphtheria Diagnosis Expert System Implementation

The implementation of the Diphtheria Diagnosis Expert System (DDES) culminated in a comprehensive evaluation of its performance, focusing on accuracy, efficiency, and adaptability. The results obtained from rigorous testing and validation phases provided valuable insights into the potential efficacy of the system in the realm of diphtheria diagnosis. One of the primary metrics assessed was the diagnostic accuracy of the DDES. The system demonstrated a notable ability to analyze clinical data and provide accurate diagnostic outcomes, showcasing its potential as a reliable tool for healthcare professionals. Performance metrics, including sensitivity, specificity, and positive predictive value, were calculated to quantitatively measure the system's ability to correctly identify both positive and negative cases of diphtheria.

In order to benchmark the DDES against existing diagnostic methods, a comparative analysis was conducted. The expert system's outcomes were juxtaposed with those derived from conventional diagnostic approaches such as clinical assessments and microbiological culture. This comparative evaluation not only validated the accuracy of the DDES but also highlighted potential advantages in terms of speed, especially crucial in the context of infectious diseases where timely diagnosis is paramount.

The DDES exhibited commendable adaptability and generalization capabilities. Through training and validation phases, the system demonstrated the ability to learn from diverse datasets and adapt its diagnostic criteria accordingly. This adaptability was particularly crucial in handling cases with atypical presentations, emphasizing the potential of the expert system to contribute to the diagnostic landscape by addressing the challenges associated with varied manifestations of diphtheria.

Simulating real-world clinical scenarios provided a practical assessment of the DDES's performance. The system was subjected to a battery of test cases representing a spectrum of diphtheria severity and diverse patient demographics. This real-world testing not only reinforced the accuracy demonstrated in controlled environments but also showcased the system's robustness and reliability when faced with the complexities inherent in actual clinical settings.

The results also prompted considerations of the ethical implications associated with the implementation of the DDES. Privacy and data security measures were scrutinized to ensure compliance with ethical standards. The ethical framework surrounding the use of an expert system in the diagnostic process, including issues related to informed consent and transparency, was carefully addressed.

Feedback from healthcare professionals who interacted with the DDES during testing provided valuable qualitative insights. User perspectives on the system's user-friendliness, interpretability of results, and integration into clinical workflows were considered. This user-centric approach aimed to enhance the practicality and acceptance of the DDES within the medical community.

3.2 Implications of the Diphtheria Diagnosis Expert System

The successful implementation of the Diphtheria Diagnosis Expert System (DDES) carries profound implications for the field of infectious disease diagnosis, public health, and patient care. The outcomes of this research have far-reaching consequences that extend beyond the realm of diphtheria and can potentially reshape the landscape of diagnostic methodologies.

The DDES, with its commendable diagnostic accuracy and adaptability, holds the potential to significantly enhance the accuracy of diphtheria diagnoses. By leveraging fuzzy logic and machine learning, the system has demonstrated an ability to discern subtle patterns and variations in clinical data, mitigating the limitations associated with conventional methods that may overlook atypical presentations.

The rapid diagnostic capabilities of the DDES have crucial implications for public health, especially in the context of infectious diseases. Timely identification of diphtheria cases allows for prompt initiation of targeted interventions, such as the administration of antitoxin therapy and the implementation of isolation measures. This can contribute to the containment of outbreaks and the prevention of further transmission within communities.

The efficiency of the DDES in providing swift diagnoses has implications for resource optimization within healthcare systems. The system's ability to deliver results in a timely manner reduces the reliance on resource-intensive methods like microbiological culture, potentially leading to cost savings and more effective allocation of healthcare resources.

The adaptability and generalization capabilities exhibited by the DDES make it well-suited for handling the evolving nature of infectious diseases. As pathogens and their presentations may change over time, the DDES's capacity to learn from new data ensures that it can adapt to emerging patterns and contribute to the continuous improvement of diagnostic accuracy.

Positive user feedback on the DDES's user-friendliness and interpretability has implications for its seamless integration into clinical practice. Healthcare professionals may find value in incorporating the expert system into their decision-making processes, potentially improving the efficiency and accuracy of diphtheria diagnoses.

The successful development and implementation of the DDES contribute to the broader field of computational diagnosis and artificial intelligence in healthcare. This research sets a precedent for the application of fuzzy logic and expert systems in addressing diagnostic challenges associated with infectious diseases, paving the way for further advancements and innovations in this rapidly evolving field.

Ethical implications surrounding patient privacy, consent, and transparency in the use of an expert system are paramount. The positive outcomes of this research underscore the importance of integrating ethical considerations into the development and deployment of similar systems. Ensuring patient-centric care and maintaining the highest ethical standards are critical for the successful adoption of such technologies in healthcare settings.

3.3 Significance of the Developed Expert System and Its Potential Impact on Diphtheria Diagnosis

The development of the Diphtheria Diagnosis Expert System (DDES) represents a significant leap forward in the field of infectious disease diagnosis, specifically addressing the challenges associated with diphtheria. The potential impact of this expert system on diphtheria diagnosis is profound, holding considerable promise for improving accuracy, timeliness, and overall public health outcomes.

The DDES, built upon fuzzy logic and machine learning, introduces a level of precision and accuracy that transcends traditional diagnostic methods. By considering the nuanced and often subtle variations in clinical presentations, the expert system enhances diagnostic specificity, reducing the likelihood of misdiagnoses or overlooking atypical cases. This heightened accuracy is pivotal for ensuring targeted and effective treatment strategies.

The swift and efficient diagnostic capabilities of the DDES address a critical aspect of infectious disease management: timely intervention. The rapid identification of diphtheria cases enables healthcare professionals to initiate treatment promptly, particularly crucial for a disease with the potential for rapid progression and severe complications. Early administration of antitoxin therapy and other appropriate interventions can significantly improve patient outcomes.

In the broader context of public health, the DDES has the potential to make substantial contributions to disease control and prevention efforts. Rapid identification of diphtheria cases allows for the swift implementation of public health measures, including isolation of affected individuals and targeted vaccination campaigns. This proactive approach is instrumental in curbing the spread of the disease within communities and preventing outbreaks.

The adaptability and generalization capabilities of the DDES are particularly significant in the context of infectious diseases with diverse clinical presentations. Diphtheria, known for its variability in symptomatology, benefits from a diagnostic tool that can adapt to evolving patterns. The expert system's ability to learn from diverse datasets ensures its relevance across different populations and geographic regions.

By providing rapid and accurate diagnoses, the DDES contributes to resource optimization within healthcare systems. The efficiency of the expert system reduces the dependence on resource-intensive diagnostic methods, potentially leading to cost savings and more efficient allocation of healthcare resources. This is especially pertinent in settings with limited resources, where streamlined diagnostic processes can have a cascading impact on overall healthcare delivery.

The DDES serves as a beacon of innovation in diagnostic methodologies, paving the way for the integration of computational intelligence in healthcare. The successful application of fuzzy logic and machine learning in infectious disease diagnosis opens avenues for further research and development, not only for diphtheria but for a broader spectrum of infectious diseases and medical conditions.

Ultimately, the significance of the DDES lies in its potential to contribute to patient-centric care and improved health outcomes. By enhancing diagnostic accuracy and facilitating timely interventions, the expert system plays a crucial role in minimizing the impact of diphtheria on individual patients. This patient-focused approach aligns with the broader goals of healthcare – to improve the quality of life and well-being of individuals affected by infectious diseases.

3.4 Comparison of Research Results with Previous

The DDES, with its incorporation of fuzzy logic, showcases an elevated level of diagnostic accuracy. By considering nuanced variations in clinical presentations, the system demonstrates a potential improvement in specificity and sensitivity. Earlier research often struggled with the subtle nuances of diphtheria symptomatology, leading to instances of misdiagnosis. The precision observed in the current research represents a marked enhancement over conventional diagnostic methods.

The DDES introduces rapid diagnostic capabilities, presenting results in a notably shorter timeframe compared to traditional methods. This efficiency is a significant improvement, facilitating swift interventions and timely responses to potential outbreaks. Comparisons with earlier methodologies, which could involve time-consuming microbiological culture, highlight the efficiency gains achieved by the DDES. The speed of diagnosis is a crucial factor in infectious disease management, and the current research demonstrates a commendable advancement.

The DDES's adaptability to diverse clinical scenarios is a standout feature, learning from various datasets to refine its diagnostic criteria. This adaptability addresses the challenges associated with the varied manifestations of diphtheria. Earlier systems may have struggled with atypical presentations, potentially leading to delayed or inaccurate diagnoses. The DDES's ability to adapt signifies a notable progression in addressing the complex nature of diphtheria cases.

Resource optimization is a key outcome of the DDES, reducing dependence on resource-intensive diagnostic methods. This aspect is particularly significant for healthcare systems aiming to allocate resources efficiently. Comparisons reveal a shift towards more efficient resource utilization. The potential cost savings associated with the DDES represent a marked improvement over previous research, aligning with the imperative for sustainable and cost-effective healthcare solutions.

Ethical considerations, including privacy and transparency, are explicitly addressed in the current research. Positive user feedback underscores the user-friendly nature of the DDES, contributing to its potential acceptance within the medical community. Ethical considerations and user feedback may have been less emphasized in earlier research. The current research demonstrates an evolution towards a more conscientious and user-centric approach, aligning with the ethical standards expected in healthcare technology.

The DDES exhibits potential integration into clinical workflows, emphasizing its practical utility for healthcare professionals. This integration represents a crucial step toward the seamless incorporation of advanced diagnostic tools into existing medical practices. Comparisons suggest a progression from potential barriers observed in earlier attempts to integrate similar systems into clinical workflows. The DDES's alignment with user needs and clinical realities indicates a positive evolution in the integration of expert systems.

The DDES demonstrates a potential for significant impact on disease management. Early interventions, accurate diagnoses, and outbreak control capabilities position the expert system as a valuable asset in the broader landscape of infectious disease management. While earlier research may have laid the groundwork for computational diagnostic approaches, the DDES represents a substantial progression in terms of its potential impact on disease management. The comprehensive nature of its contributions reflects an advancement in the collective understanding of how expert systems can effectively contribute to healthcare outcomes.

4. CONCLUSION

The research journey into developing the Diphtheria Diagnosis Expert System (DDES) utilizing fuzzy logic stands as a significant milestone in the field of infectious disease diagnosis. This investigation has illuminated the potential of advanced computational methodologies to revolutionize the identification and management of diphtheria cases, offering a more precise, rapid, and adaptable approach compared to conventional diagnostic methods. The outcomes of this research showcase the DDES's prowess in enhancing diagnostic accuracy, particularly in navigating the complex and varied presentations of diphtheria. The incorporation of fuzzy logic has proven instrumental in capturing the subtleties of clinical data, thereby minimizing the risk of misdiagnoses and providing a level of specificity crucial for effective disease management. The speed and efficiency demonstrated by the DDES address a critical need in infectious disease scenarios, where timely interventions can significantly alter the course of patient outcomes and contribute to the control of potential outbreaks. The system's adaptability to diverse clinical presentations further positions it as a versatile tool capable of learning from evolving datasets, ensuring relevance across different populations and geographic regions. Resource optimization, a crucial consideration in modern healthcare, takes center stage in the DDES's contribution. By streamlining diagnostic processes and reducing dependence on resource-intensive methods, the expert system not only enhances efficiency but also offers potential cost savings, making it a valuable asset for healthcare systems striving to deliver high-quality care with limited resources. The ethical considerations woven into the fabric of this research underscore a commitment to responsible technological deployment. The attention to privacy, transparency, and user feedback reflects a conscientious approach to integrating advanced computational tools into the healthcare landscape. This ethical foundation is essential for fostering trust among healthcare professionals and patients alike. The integration potential of the DDES into clinical practice represents a bridge between cutting-edge technology and the realities of healthcare delivery. The system's user-friendly nature and alignment with clinical workflows position it as a practical and valuable tool for healthcare professionals, potentially transforming the diagnostic landscape in real-world settings. In the broader context of infectious disease management, the DDES emerges as a beacon of innovation. Its potential impact on disease control, through early interventions, accurate diagnoses, and outbreak response capabilities, holds the promise of improving patient outcomes and bolstering public health efforts.

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