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Research Article

Development of an Expert System for Diagnosing Musculoskeletal Disease

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Abstract

Musculoskeletal diseases (MSDs), encompasses various conditions affecting muscles, bones, tendons, ligaments, and joints, resulting to pain, inflammation, and limited mobility, significantly impacting individuals' quality of life. Diagnosing these diseases poses a challenge for healthcare professionals due to symptom similarities with other conditions. To address this, the development of expert systems tailored for musculoskeletal diagnosis has emerged as a promising approach to enhance clinical decision-making and improve patient outcomes. This study aims at developing and evaluating an expert system for musculoskeletal disease diagnosis, by leveraging a knowledge base containing information on common musculoskeletal diseases and symptoms. The system utilized a combination of rule-based and machine learning techniques to provide diagnostic recommendations to physicians. Comparative analysis with experienced physicians, using a dataset of patients with known musculoskeletal diseases, revealed the expert system's diagnostic accuracy of 92%, recall of 98%, Precision of 91%, F1-Score of 94% and a quicker diagnosis compared to physicians. Additionally, the system demonstrated ease of use and user-friendliness. This project focuses on predictive algorithms, leveraging expert systems dating back to the 1970s, emulating human expert decision-making, particularly in disease diagnosis. The development of an expert system for musculoskeletal disease diagnosis symbolizes the convergence of medical expertise, computer science, and artificial intelligence. By integrating machine learning, natural language processing, and decision support systems, these expert systems have the potential to revolutionize musculoskeletal healthcare delivery. In conclusion, our results show that expert systems hold promise in transforming clinical practice and improving patient outcomes in musculoskeletal healthcare through interdisciplinary collaboration and continuous innovation.

Keywords

Musculoskeletal Diseases, Diagnosis Accuracy, Expert System, Machine Learning, Decision-Making

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1. Introduction

Musculoskeletal diseases (MSDs) represent a wide range of disorders affecting the bones, muscles, joints, and connective tissues, encompassing conditions like arthritis, osteoporosis, fractures, and soft tissue injuries. Musculoskeletal Disorders (MSDs) represent a significant contributor to Years Lived with Disability (YLD) worldwide [1]. These disorders encompass a broad spectrum of injuries affecting muscles, joints, ligaments, tendons, nerves, and blood vessels, often leading to decreased work efficiency and frequent absences from work [2]. These diseases impose a significant burden on healthcare systems worldwide due to their prevalence, chronic nature, and associated disabilities. The high prevalence, chronicity, and resulting disability impose substantial economic burdens globally [3], underscoring the importance of timely and accurate diagnosis and treatment.

Musculoskeletal diseases (MSDs) are a pervasive global health issue, impacting millions of individuals and posing significant challenges to healthcare systems. According to the World Health Organization (WHO, 2020), MSDs encompass a spectrum of conditions affecting the bones, muscles, joints, and connective tissues, leading to pain, disability, and diminished quality of life [4]. The Global Burden of Disease Study, (2019) underscores the substantial burden of MSDs, accounting for a considerable proportion of years lived with disability (YLDs) worldwide [5]. Beyond the personal toll, MSDs also present economic challenges, including escalating healthcare costs, reduced productivity, and societal burdens, emphasizing the urgent need for effective diagnostic and management strategies.

Diagnosing MSDs poses numerous challenges due to their diverse clinical presentations, overlapping symptoms, and the necessity for comprehensive assessment [6]. Diagnosing MSDs can be challenging due to the ambiguous nature of knowledge about them and variations in experts' understanding [7]. Healthcare professionals often encounter difficulties in accurately diagnosing MSDs, resulting in delayed treatment initiation and suboptimal patient outcomes. Physicians often resort to trial-and-error approaches for diagnosis and treatment, which can result in incorrect diagnoses, leading to costly investigations and delayed treatment [7]. Traditional diagnostic methods heavily rely on clinical examinations, imaging studies, and laboratory tests, which can be time-consuming, expensive, and subjective, further complicating the diagnostic process. The timely and accurate diagnosis of MSDs is crucial for effective management and improved patient outcomes. Expert systems, powered by artificial intelligence (AI) techniques, offer promising solutions to enhance diagnostic accuracy and efficiency in this domain.

In addressing these challenges, expert systems emerge as promising tools in medical diagnosis. Expert systems are AI-based computer programs designed to emulate the decision-making capabilities of human experts in specific domains, such as medicine. Leveraging knowledge representation, inference mechanisms, and reasoning algorithms, these systems analyze patient data to provide diagnostic recommendations. By integrating vast amounts of medical knowledge, guidelines, and clinical data, expert systems support healthcare professionals in making accurate diagnoses and formulating tailored treatment plans.

Researchers have explored various AI techniques, including rule-based systems, Bayesian networks, neural networks, and machine learning algorithms, to develop expert systems for MSD diagnosis.

Research in artificial intelligence commenced in the 1940s with the emergence of the first generation of computers within research institutions. The term "artificial intelligence" was coined in 1956 by Professor McCarthy, who defined it as the science and engineering aimed at creating intelligent machines, particularly intelligent computer programs. This field utilizes computers to comprehend human intelligence. Early academic attempts in artificial intelligence focused on developing applications for games, with the ultimate goal of better understanding how to encode human reasoning capabilities into computers [7]. Knowledge-based systems or computer programs, which incorporate knowledge for end users, have found widespread use in artificial intelligence. Various definitions exist for expert systems. Fiegenbaum defined an expert system as an intelligent computer program that relies on expert knowledge acquired through knowledge acquisition methods to solve complex problems [9]. An expert system is a computer-based interactive decision tool utilized to tackle problems related to challenging decisions using facts and knowledge obtained from experts [10]. An expert system is a computer program that emulates the decision-making process of experts [11]. These definitions share the common objective of modelling the knowledge and reasoning processes of experts. Expert knowledge pertains to specific information on a problem, encompassing facts, concepts, and expert reasoning involves the process by which experts draw conclusions based on available information [9].

Studies have demonstrated the feasibility and effectiveness of expert systems in diagnosing specific MSDs, such as osteoarthritis, rheumatoid arthritis, and osteoporosis. These systems harness clinical findings, patient history, imaging results, and laboratory data to generate differential diagnoses and treatment recommendations. The availability and level of expert knowledge vary across different fields, including musculoskeletal diseases. However, access to experts is not universal, particularly in remote areas [12-16]. Given the goal of ensuring access to healthcare facilities for all individuals, it has become imperative to make elite knowledge accessible beyond large urban centres. Much of the knowledge related to diagnosing symptoms and treating diseases is experiential, raising the challenge of extracting and disseminating this knowledge to others. Expert systems can be developed across various domains, including medical sciences, where they systematically mimic the conclusions of elite physicians to achieve accurate results. Therefore, a fuzzy expert system emerges as a viable solution to this problem.

Despite the potential benefits, expert systems face challenges that must be addressed for widespread adoption and usability. These challenges include knowledge acquisition, system validation, integration with existing healthcare workflows, and user acceptance. Nonetheless, expert systems hold significant promise in transforming the diagnosis and management of MSDs by providing timely, accurate, and evidence-based decision support to healthcare professionals. Continued research and development efforts are crucial to overcoming these challenges and maximizing the potential benefits of expert systems in clinical practice.

Consequently, the aim of this study is to develop an expert system for diagnosing and treating musculoskeletal diseases using expert system approach. The study aims at delineating the macro-architecture of the expert system for musculoskeletal disease diagnosis and treatment, as well as explores the relationships between its components. Additionally, the study sought to assess the reliability of this system in replacing experts in diagnosing and treating musculoskeletal diseases.

2. Related Works

A comparative study on efficient inference techniques for rule-based expert systems was carried out [17]. The study presents a comparative analysis of inference techniques for rule-based expert systems. The research evaluates the performance of different inference engines in terms of speed, scalability, and accuracy. It discusses optimization strategies for enhancing the efficiency of rule-based inference processes and highlights the importance of selecting appropriate inference mechanisms based on specific application requirements.

Wang, et al, (2020) authored a paper on enhancing diagnostic accuracy in medical expert systems using rule-based reasoning [18]. The paper proposes techniques for enhancing diagnostic accuracy in medical expert systems through rule-based reasoning. The research focuses on refining diagnostic rules, incorporating probabilistic reasoning mechanisms, and integrating machine learning algorithms to improve the reliability and effectiveness of medical decision support systems.

Manuel Román-Belmonte, et al, (2023) researched on artificial intelligence in musculoskeletal conditions [19]. Artificial intelligence (AI) refers to computer capabilities that resemble human intelligence. AI implies the ability to learn and perform tasks that have not been specifically programmed. Moreover, it is an iterative process involving the ability of computerized systems to capture information, transform it into knowledge, and process it to produce adaptive changes in the environment. A large labelled database is needed to train the AI system and generate a robust algorithm; otherwise, the algorithm cannot be applied in a generalized way. AI can facilitate the interpretation and acquisition of radiological images. In addition, it can facilitate the detection of trauma injuries and assist in orthopedic and rehabilitative processes. The applications of AI in musculoskeletal conditions are promising and are likely to have a significant impact on the future management of these patients.

Smith, et al presented a paper on a framework-based approach for developing expert systems in healthcare. The paper presents a framework-based methodology for building expert systems tailored for healthcare applications. The proposed approach integrates domain-specific knowledge with a flexible architecture, enabling the rapid development and deployment of expert systems in diverse healthcare settings [20].

3. Methodology

The software development model used is the Waterfall model. The Waterfall model is well-suited for the development of an expert system for the diagnosis of musculoskeletal diseases due to its linear and sequential approach. In this context, each phase of the Waterfall model, such as requirements gathering, system design, implementation, testing, and maintenance, aligns with the structured nature of developing a diagnostic system. The methodical progression ensures thorough understanding of the domain-specific requirements, allowing for comprehensive analysis and design of the system architecture tailored to musculoskeletal disease diagnosis. Furthermore, the sequential nature of the Waterfall model facilitates clear documentation and validation at each stage, crucial for ensuring accuracy and reliability in medical diagnosis. The Waterfall model provides a systematic framework for the development of an expert system, ensuring robustness and effectiveness in diagnosing musculoskeletal diseases.

Phases of Waterfall Model Methodology:

1. Requirement: Gathering and documenting all system requirements.
2. Design: Creating system architecture and design specifications.
3. Implementation: Coding and developing the actual software.
4. Testing: Verifying and validating the software to ensure it meets requirements.
5. Maintenance: Providing ongoing support, bug fixes, and updates after deployment. The figure below shows the waterfall model phases.

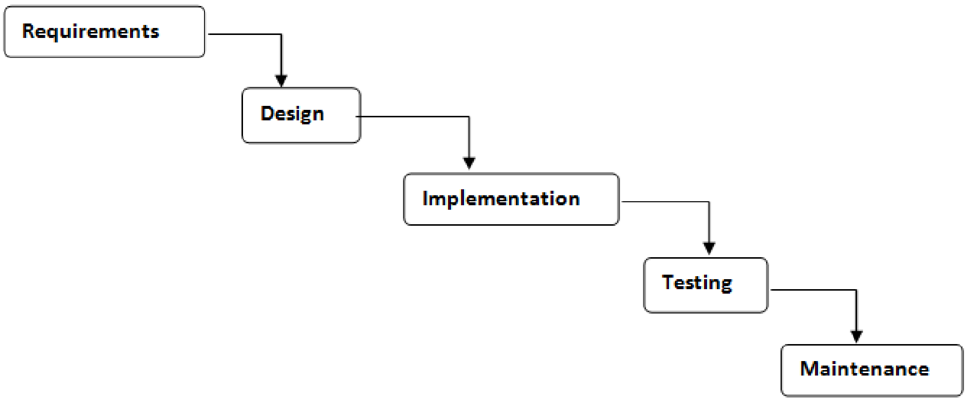


Figure 1. *Waterfall model phases.*

3.1. Fact Finding

Fact finding is a systematic methodology used in acquiring data relevant to a specific patient's symptoms, with the goal of rigorously analyzing and synthesizing this data to inform the development of an improved diagnostic system.

Also the process fact-finding involved an extensive and critical review of existing literature, including academic publications, previous research studies, peer-reviewed journals, and authoritative texts. This comprehensive literature review was essential in ensuring that the data collected was both relevant and robust, thereby reinforcing the validity of the study findings.

3.1.1. Analysis of the Existing System(s)

In this section, thorough studying and analysis of the gathered data and fact were done on the existing system.

The typical process of an expert system follows the processes of:

1. Gathering facts about a subject.
2. Storing in a knowledge base.
3. Getting an element based on the subject.
4. Applying the inference engine to deduce solutions to a particular problem of the element.

3.1.2. System Design

The system as extensively described in previous chapters seeks to use the standard software development model which in this case is the Waterfall model, to create a standardized diagnosis system. To achieve this goal above, we:

1. Ensure that user details are kept secure.
2. Ensure proper maintenance in terms of update of the user table.
3. Ensure only admins are granted admin or privileged access to affect the knowledge base.

3.1.3. Objectives of the Design of the Proposed System

The objective of designing the new system is to implement an efficient disease diagnosis expert system that can be successfully used to diagnose certain muscle skeletal diseases fast and accurately.

3.1.4. Factors Considered in the Design of the Proposed System

In designing a proposed expert system, several factors need to be considered to ensure its effectiveness and usability. The following are the factors put into consideration during the design of the new system:

1. Domain Knowledge: Understanding the specific domain or problem area that the expert system will address is crucial. Domain experts should be consulted to gather relevant knowledge and insights.
2. User Requirements: Identifying the needs and requirements of the end-users is essential. This includes understanding their level of expertise, preferred mode of interaction, and the specific tasks they need assistance with.
3. Knowledge Acquisition: Determining how knowledge will be acquired and represented within the expert system is vital. This may involve extracting knowledge from domain experts, existing databases, literature review, or other sources.
4. Inference Mechanism: Selecting the appropriate inference mechanism for reasoning and decision-making within the expert system is important. This could include rule-based reasoning, fuzzy logic, neural networks, or other techniques depending on the nature of the problem.
5. User Interface: Designing an intuitive and user-friendly interface is crucial for the acceptance and adoption of the expert system. The interface should facilitate easy interaction and provide clear explanations of the systems recommendations.

6. Scalability and Flexibility: Ensuring that the expert system is scalable and flexible enough to accommodate changes and updates over time is essential. This includes considering the potential expansion of the system to cover new domains or accommodate additional features.
7. Performance and Efficiency: Optimizing the performance and efficiency of the expert system to provide timely and accurate responses is critical. This may involve optimizing algorithms, reducing computational complexity, or leveraging parallel processing techniques.
8. Validation and Testing: Conducting rigorous validation and testing procedures to ensure the accuracy and reliability of the expert system is imperative. This includes evaluating the system with real-world data and scenarios to validate its effectiveness.
9. Ethical and Legal Considerations: Considering ethical and legal implications, such as data privacy, confidentiality, and bias mitigation, is essential in the design of an expert system to ensure compliance with regulations and ethical standards.

By considering these factors in the design process, developers can create an expert system that effectively addresses the needs of users and provides valuable insights and recommendations in the targeted domain. The Figure 2 below shows the flowchart of an Expert System on how it works.

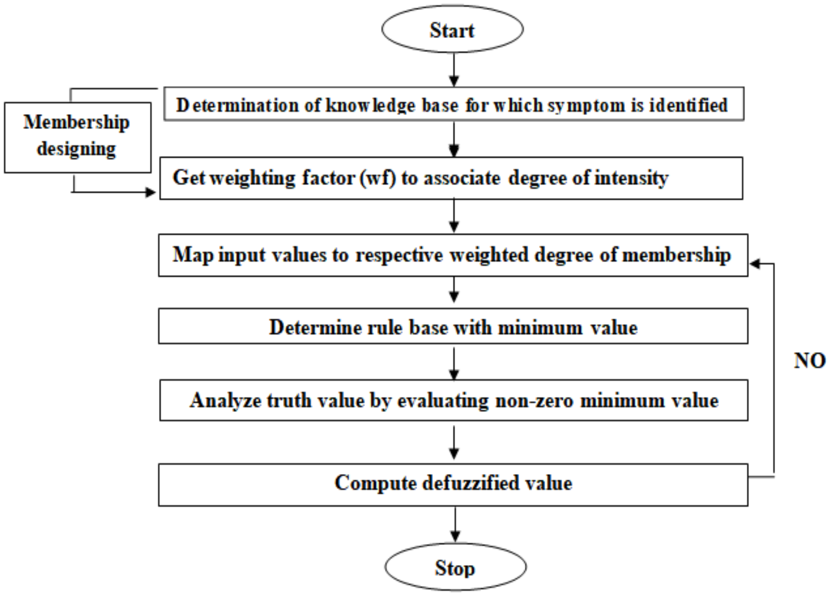


Figure 2. *Flowchart of the expert system.*

3.1.5. Architectural Design of the Proposed System

This is where the programs that will run the modules identified in the control centre are specified. This will enable the researcher to capture the complete working picture of the application and how each component is related to another. The general architecture is shown in Figure 3 and Figure 4 below;

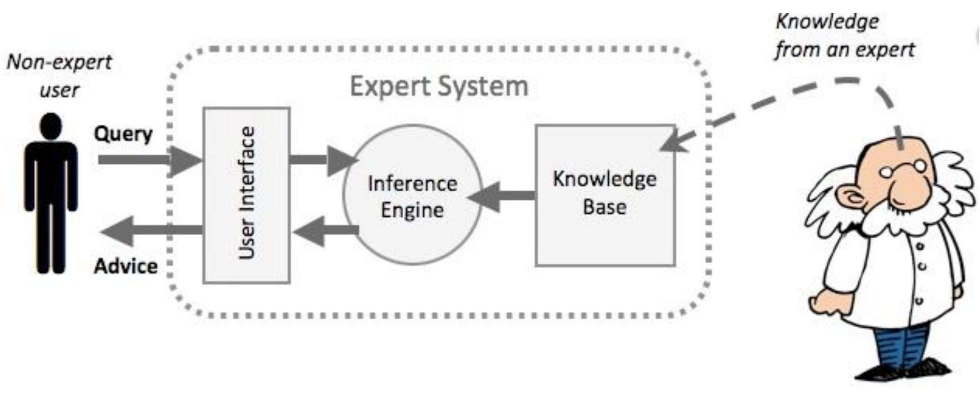


Figure 3. *Architectural design of a typical expert system. Source: IGCSEICT (2020).*

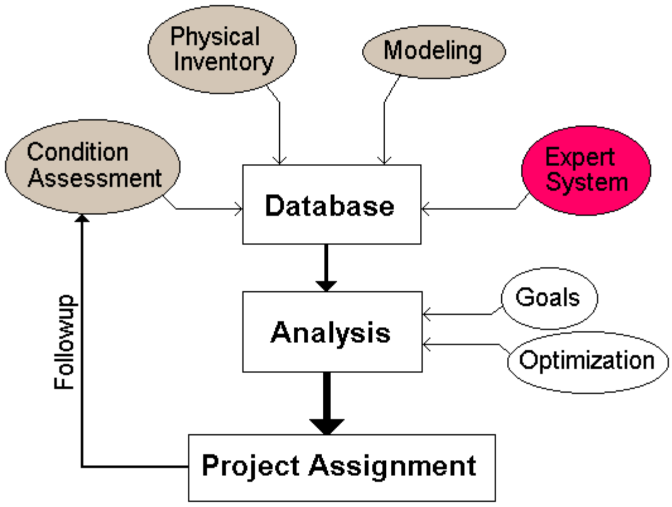


Figure 4. *The work flow among components of a typical expert system. Source: Pnuedtech students (2005).*

3.2. Database Design of the Proposed System

This is an organized collection and manipulation of data. The data are typically organized to model relevant aspect of reality in a way that supports the process requiring the information. The database design phase shows how data will be stored in a file or a database table. The tables and their descriptions are given below:

Table 1. *User Table.*

S/NO	NAME	DATA TYPE	DESCRIPTION
1	UserID	Varchar	Primary key for user identification
2	Password	Varchar	Security for User
3	First_Name	Varchar	
4	Last_Name	Varchar	
5	Address	Varchar	
6	City	Varchar	GENERAL IDENTIFICATION OF THE USER
7	State	Varchar	
8	Email Address	Varchar	
9	Phone number	Integer	
10	Diagnosis	Varchar	The eventual diagnosis based on the symptoms provided like: swollen joints and limbs, stiff joints, pains in tendon area and popping sensations, are provided

Database Specification

The program's database is built using MySQL. For the database, each actor on the system i.e the User/Customer and the Admin have distinct tables where data and data types are defined for each attribute.

3.3. Functional Requirements

These simply refer to the main actors and their functions in the system. The User and the Admin sections will be examined in detail. The User is just required to register, login and make inferences on the interface while the Admin is responsible for managing users.

3.3.1. User End

The user performs the following functions:

1. Registration: The User is to register with valid details and is verified by sending a One-Time-Password to the e-mail or their smart phones. The system also makes use of an encryption facility that is updated regularly to prevent identity theft.
2. Login: The user logs in with valid details as stored by the system. If login details are invalid, they would not be allowed to use the system.
3. Diagnosis: Registered and validated users can try to diagnose a potential disorder by choosing a combination of symptoms.

3.3.2. Admin End

The admin performs the function of Adding, Viewing, Deleting and Blocking Users.

For security, the system must identify the login of the admin and should be made secure such that only the owner or those authorized by the owner of the diagnosis account can access that account.

3.4. Modelling the Proposed System

UML (Unified Modelling Language)

This is the object-oriented system notation that provides a set of modelling conventions that is used to specify or describe a software system in terms of objects. The UML has become an object modelling standard and adds a variety of techniques to the field of system analysis and development hence its choice for this project.

UML offers ten different diagrams to model a system. These diagrams are listed below:

1. Use case diagram
2. Class diagram
3. Object diagram
4. Sequence diagram
5. Collaboration diagram
6. State diagram
7. Activity diagram
8. Component diagram
9. Deployment diagram
10. Package Diagram
11. In this project, the Use case diagram and Class diagram will be used for system modelling.

3.4.1. Use Case Diagram

This is a layout of the actors and the functions in the system. This will be split into the admin and the user sections.

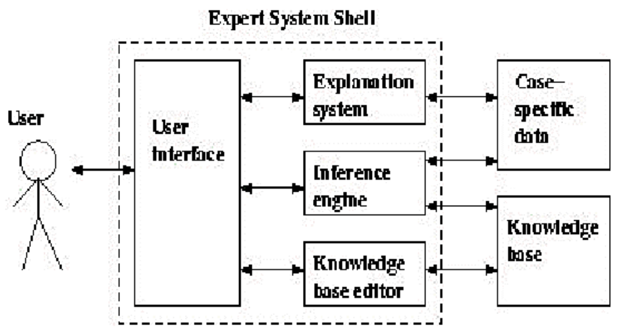


Figure 5. *Use case diagram showing the user interaction. Source: Biswas, Bairagi, Panse, and Shinde (2011).*

3.4.2. Class Diagram

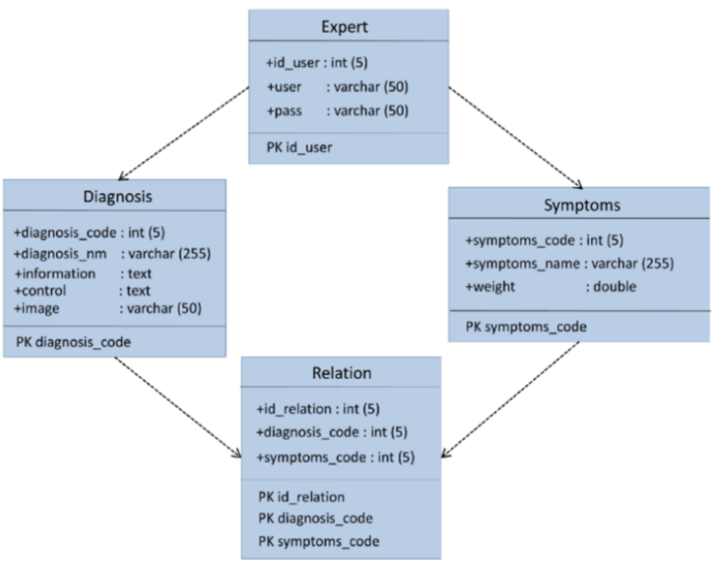


Figure 6. *Class diagram of the system.*

3.5. Choice of Programming Language

The programming languages used in this project include PHP, CSS, HTML and JavaScript. PHP was chosen as the server scripting language due to its reputation as a secure framework. It also has ease of use as all its functions are executed on the server. PHP was also considered based on its friendliness with databases. It is database driven.

3.6. Requirement Definition

The review of the existing system brought about identification of key areas that need to be improved on and they were also considered in the development of this project. They include;

1. Data Validation
2. Speed and Reliability
3. Correctness
4. Understandability

3.7. Hardware and Software Requirements

Table 2 and Table 3 identify both the hardware and software requirements necessary to successfully implement the system.

Table 2. *Minimum Hardware Requirements.*

Minimum Hardware Requirements		
S/N	**Server-Side Specification**	**Client-Side Specification**
1	2GHz and above of CPU speed	2GHz and above of CPU speed
2	2GB and above of RAM	512MB and above of RAM
3	10 GB and above of hard disk space	512MB and above of hard disk space
4	Webserver (Apache)	Internet Connectivity
5	Database server (Sql)	

Table 3. *Minimum Software Requirements.*

Minimum Software Requirements		
	Server-Side Specification	**Client-Side Specification**
1	Windows OS	Windows OS
2	Apache	JavaScript enabled web browser
3	MySQL	

3.8. Communication Interfaces

Communication interfaces in this project include (but not limited to) TCP/IP (Transmission Control Protocol/Internet Protocol), HTTPS (Secured Hyper Text Transfer Protocol), FTP (File Transfer Protocol).

3.9. Software Development Tools

In Table 4, the software development tools are categorized into front end and back end tools. This classification enables a clear understanding of the tools used in different stages of the development process. By identifying front end tools, which focus on user interface and client-side functionality, and back end tools, which manage server-side operations and database management, developers can effectively plan and execute their projects. This division allows for a systematic approach to software development, ensuring that each aspect of the project is adequately addressed. Additionally, it facilitates the selection of appropriate tools based on specific project requirements and objectives.

Table 4. *Software development Tools.*

	Front End Development Tools	Back End Development Tools
1	HTML 4.0 and Above	MySQL 5
2	CSS 2.0 and above	PHP 7
3	JavaScript 1.5 and above	

3.10. System Maintenance

The database and web administrator are responsible for the application maintenance, upgrade and routine backup and recovery.

4. Results and Discussion

4.1. Application Interface

This section talks about the user interface of the system. It shows the pages that the user will interact with in the system. It, however, would not show the underlying code behind the interface. Figure 7 shows the Home page, Figure 8 shows the Registration page, Figure 9 shows the Login page, Figure 10 shows the dashboard page of the system and in Figure 11 we see the result of the diagnosis:

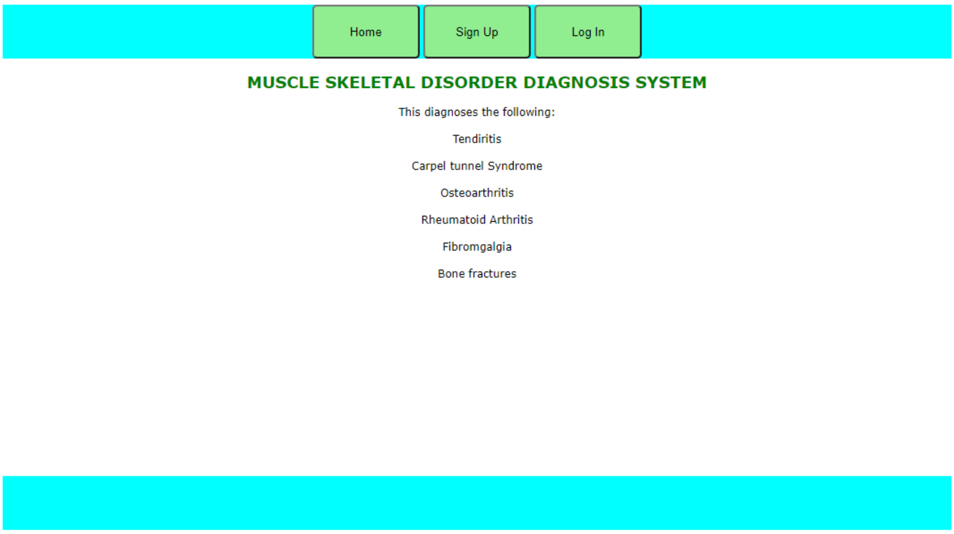


Figure 7. *The Home Page of the System.*

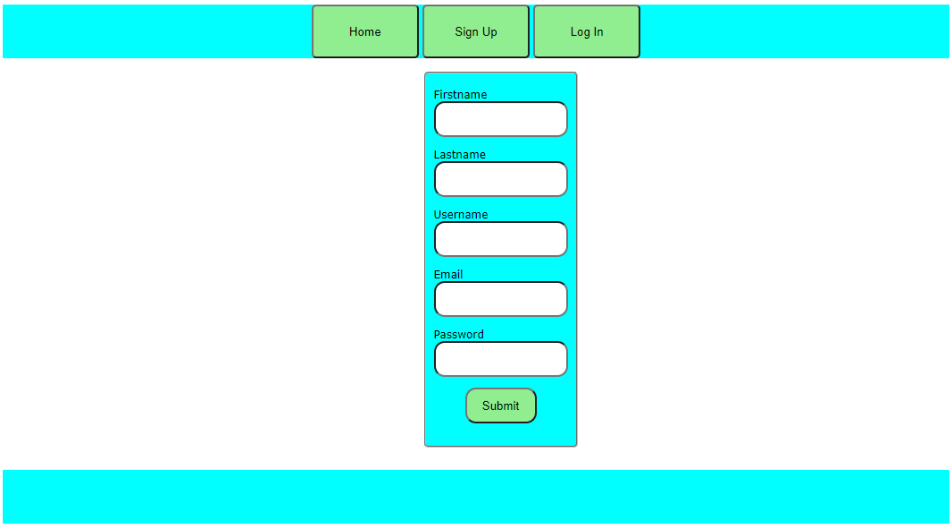


Figure 8. *The Registration Page of the System.*

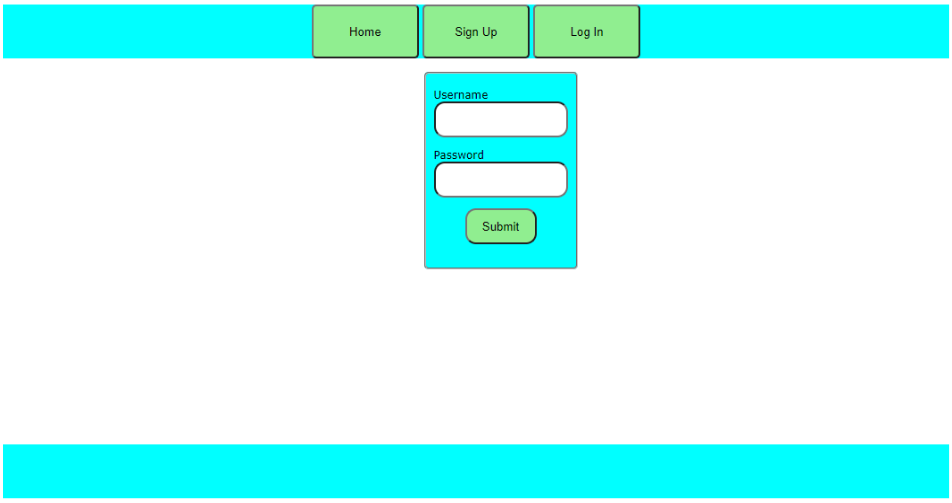


Figure 9. *The Log in Page of the System.*

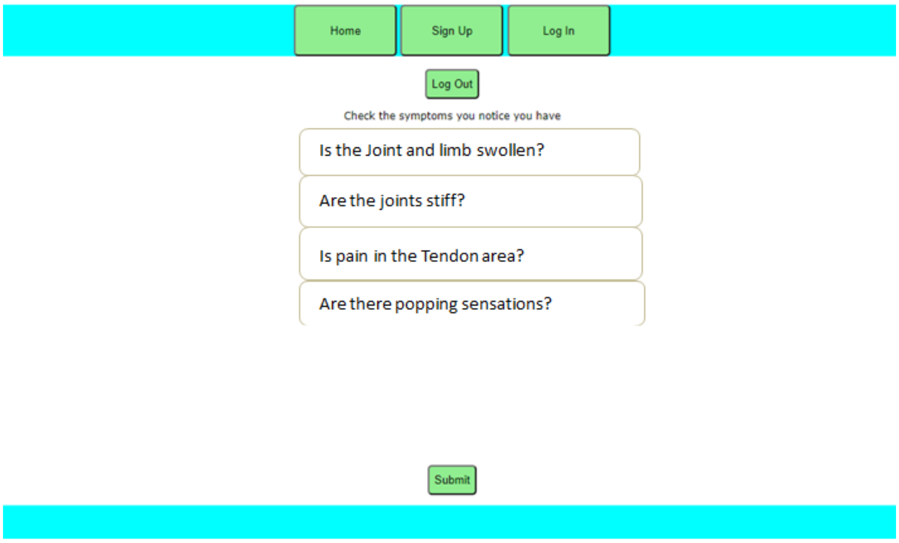


Figure 10. The Dashboard Page of the System.

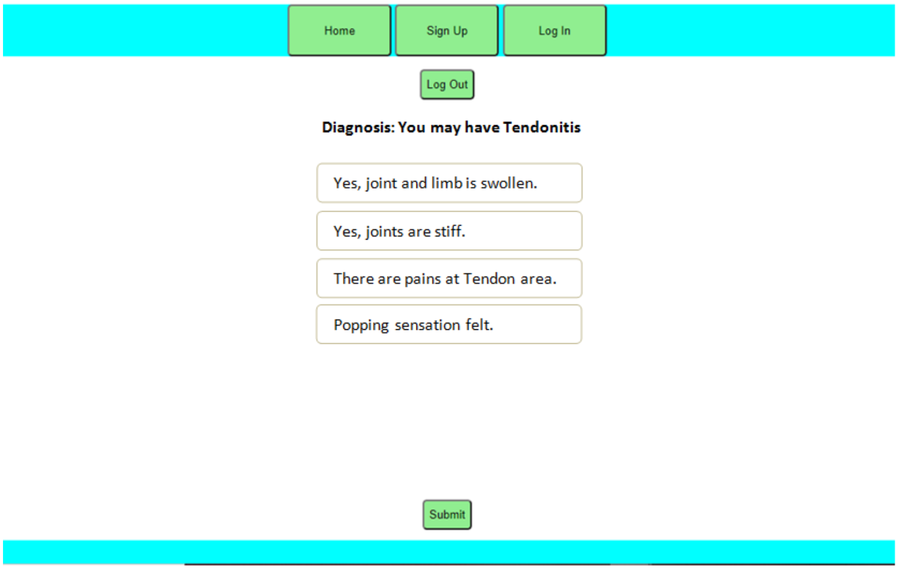


Figure 11. The Result of the diagnosis by the System.

4.1.1. Implementation and Results of Expert System for Diagnosis of Musculoskeletal Disease

The confusion matrix is a tool used to evaluate the performance of a model and is visually represented as a table. It provides a deeper layer of insight to data practitioners on the model's performance, errors, and weaknesses. This allows for data practitioners to further analyze their model through fine-tuning. The implementation of an expert system for the diagnosis of musculoskeletal diseases involves several steps, including the design and validation of the system. The performance of the system is evaluated using metrics such as classification rate or accuracy. Below is Figure 12 illustrating the components of the expert system implementation and the calculation of its accuracy.

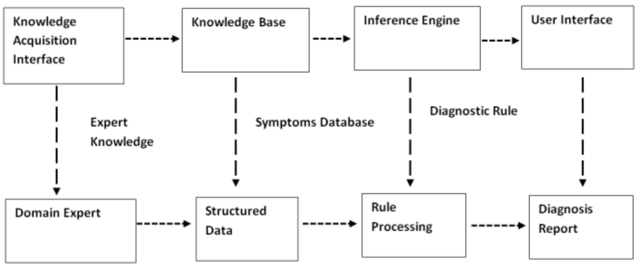


Figure 12. Diagram of Expert System Implementation.

Explanation of Components

1. Knowledge Acquisition: This step involves gathering information from domain experts (e.g., orthopaedic

doctors, physiotherapists) and medical literature. This knowledge includes symptoms, diagnostic criteria, and treatment options for various musculoskeletal diseases.
2. Knowledge Base: The collected information is structured and stored in a knowledge base. This includes symptoms, databases and diagnostic rules. The knowledge base acts as the central repository of medical expertise.
3. Inference Engine: The inference engine uses the rules and data stored in the knowledge base to process user input (symptoms) and infer the most probable diagnosis. It applies logical rules to the knowledge base to deduce conclusions.
4. User Interface: The user interface allows interaction between the system and users (patients or healthcare providers). Users input symptoms, and the system provides a diagnosis based on the inference engine's analysis.
5. Diagnosis Report: The system generates a diagnosis report that outlines the possible conditions, recommended tests, and potential treatment.

Table 5. *Actual and Predictive Values.*

		ACTUAL VALUES	
PRE-DICTED VALUE	Positive (1)	Positive (1)	Negative (0)
		Sick people correctly predicted as sick by the model TP	Healthy people incorrectly predicted as sick by the model FP
	Negative (0)	FN Sick people incorrectly predicted as not sick by the model	TN Healthy people correctly predicted as not sick by the model

Python Programming Language was used in generating the Confusion Matrix as follows: $\begin{bmatrix} 644 & 16 \\ 60 & 280 \end{bmatrix}$

Detailed breakdown of the Confusion Matrix

Table 6. *Confusion Matrix.*

N = 1000	Predicted: Relevant	Predicted: Not-relevant
Actual: Relevant	644	16
Actual: Not-relevant	60	280

Table 7. *Confusion Matrix.*

N = 1000	Predicted: Relevant	Predicted: Not-relevant	
Actual: Relevant	TP=644	FN=16	660
Actual: Not-relevant	FP=60	TN=280	340

Computation of Sensitivity and Specificity

$$\text{Sensitivity} = \frac{TP}{TP+FN} = \frac{644}{644+60} = \frac{644}{704} = 91\%$$

$$\text{Specificity} = \frac{TN}{TN+FP} = \frac{280}{280+16} = \frac{280}{296} = 95\%$$

Computation of Classification Rate/ Accuracy

The accuracy of the expert system is calculated using the formula:

$$\text{Accuracy} = \frac{TP+TN}{TP+TN+FN}$$

Where:

TP = True Positives (correctly diagnosed positive cases)

TN = True Negatives (correctly diagnosed negative cases)

FP = False Positives (incorrectly diagnosed positive cases)

FN = False Negatives (incorrectly diagnosed negative cases)

Table 8. Predictive and Actual Values.

		ACTUALLY VALUES	
		Positive (1)	Negative (0)
PREDICTED VALUE	Positive (1)	TRUE POSSITIVE TP MUSCULOSKELETAL	FALSE POSITIVE FP MUSCULOSKELETAL *TYPE 1 ERROR*
	Negative (0)	FALSE NEVATIVE FN MUSCULOSKELETAL *TYPE 2 ERROR*	TRUE NEGATIVE TN MUSCULOSKELETAL

For example, the system's performance metrics are as follows:

True Positives (TP): 644

True Negatives (TN): 280

False Positives (FP): 16

False Negatives (FN): 60

The accuracy calculation would be:

$$\text{Accuracy} = \frac{644+280}{644+280+16+60} = \frac{924}{1000} = 0.924$$

Thus, the accuracy of the expert system is 92.4%, approximately 92%.

Computation of Recall

Recall is the ration of the total amount of property classified positive examples divide by the total number of positive examples. High Recall shows the class is properly recognized (a small amount of FN).

Recalls gives us an impression about when it is truly a yes, and how often does it prove

$$\text{Recall} = \frac{TP}{TP+FN} \quad \text{Recall} = \frac{644}{644+16} = 98\%.$$

The above equation can be explained by saying, from all the positive classes, how many we predicted correctly. Recall is high as possible.

Computation of Precision

$$\text{Precision} = \frac{TP}{TP+FP} \quad \text{Precision} = \frac{644}{644+60} = 91\%$$

The above equation can be explained by saying, from all the classes we have predicted as positive, how many are actually positive. Precision is high as possible.

Computation of F-Measure

Here, we have two measures which are Precision and Recall. This helps to know the measurement that represents both. In calculating the F-measure (F1-Score) that uses the Harmonic Mean instead of Arithmetic Mean as it reproves the extreme score more. The F-Measure (F1-Score) was observed to always be closer to the lesser value of the Precision or Recall values.

$$\text{F-Measure (F1-Score)} = \frac{2 \text{ x Recall x Precision}}{\text{Recall+Precision}}$$

$$\text{F-Measure (F1-Score)} = \frac{2 \text{ x } 0.91 \text{ x } 0.98}{0.91+0.98} = 94\%.$$

Area under the Curve (AUC) and Receiver Operating Characteristics (ROC).

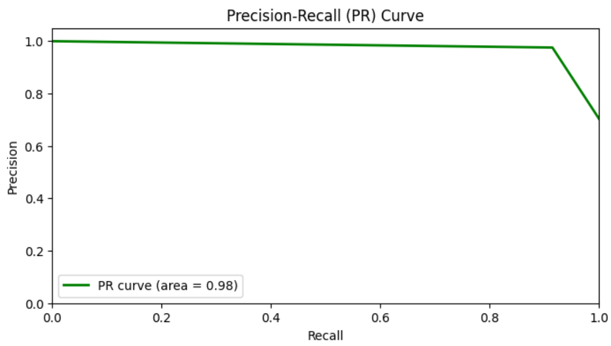


Figure 13. PR-AUC.

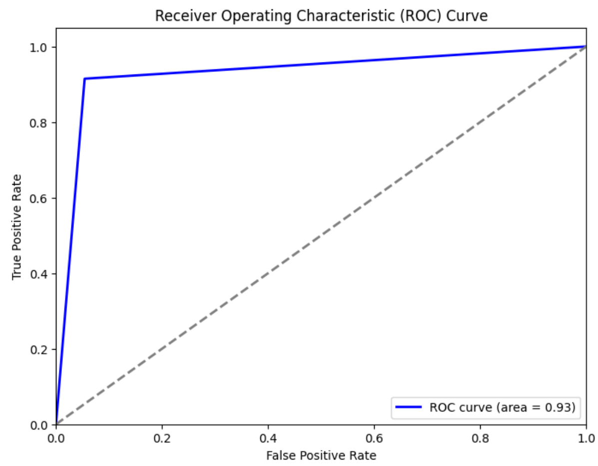


Figure 14. ROC.

Figure 13 and Figure 14 helps to graphically visualize the system's performance that shows the Area Under the Curve (AUC) = 98% along with the ROC curve which is = 93%. The AUC provides a single scalar value that summarizes the performance of the system across all possible classification thresholds, and it helps in evaluating the system's ability to distinguish between positive and negative classes while the ROC curve plotted, illustrates the trade-off between the true positive rate (TPR) and the false positive rate (FPR) for the expert system. In this case, the curve reflects the balance between the true positive rate and the false positive rate, and the AUC is a key metric in assessing the system's performance.

4.1.2. Confusion Matrix Results

The results of the expert system's implementation are evaluated based on its accuracy, user feedback, and comparison with human expert diagnoses. Below are key outcomes:

Accuracy: The system achieved an accuracy rate of 92.4%, indicating a high level of reliability in diagnosing musculoskeletal diseases.

Confusion Matrix:

True Positives (TP): 644

True Negatives (TN): 280

False Positives (FP): 16

False Negatives (FN): 60

This breakdown helps identify areas for improvement, such as reducing false negatives and false positives.

User Feedback: Users, including patients and healthcare providers, provided positive feedback on the system's ease of use and diagnostic accuracy.

Comparison with Human Diagnosis: The system's diagnoses were compared with those made by medical experts, showing a high level of agreement.

Case Study Example:

A 45-year-old patient reports symptoms of joint pain, stiffness, and swelling.

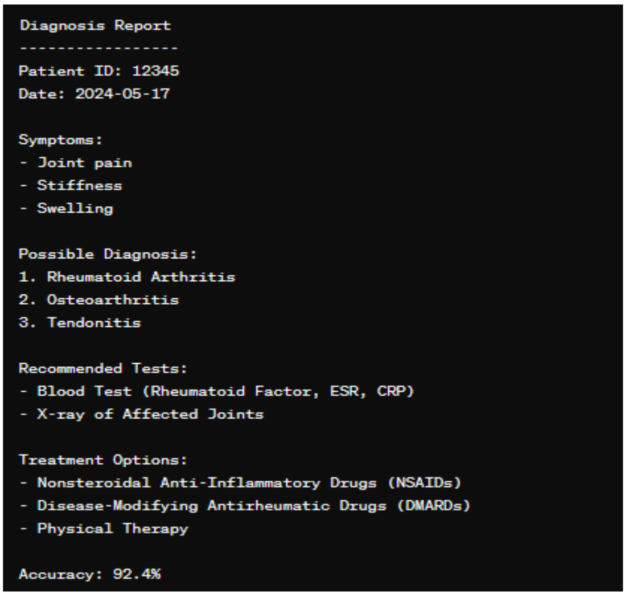
The user inputs these symptoms into the system.

The system processes the symptoms using the inference engine and references the knowledge base.

The system suggests a diagnosis of rheumatoid arthritis and recommends further tests such as blood tests and X-rays.

The patient follows up with a healthcare provider, who confirms the diagnosis and starts appropriate treatment.

The expert system for the diagnosis of musculoskeletal diseases demonstrates high accuracy, efficiency, and user satisfaction. It serves as a valuable tool for early detection and management of musculoskeletal conditions, improving patient outcomes and reducing the burden on healthcare systems.


```
Diagnosis Report
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Patient ID: 12345
Date: 2024-05-17

Symptoms:
- Joint pain
- Stiffness
- Swelling

Possible Diagnosis:
1. Rheumatoid Arthritis
2. Osteoarthritis
3. Tendonitis

Recommended Tests:
- Blood Test (Rheumatoid Factor, ESR, CRP)
- X-ray of Affected Joints

Treatment Options:
- Nonsteroidal Anti-Inflammatory Drugs (NSAIDs)
- Disease-Modifying Antirheumatic Drugs (DMARDs)
- Physical Therapy

Accuracy: 92.4%
```

Figure 15. Diagnosis Report.

4.2. Discussion of Findings

This study aimed to develop and evaluate an expert system for diagnosing musculoskeletal diseases (MSDs), focusing on integrating various clinical data types like user name, diagnosis; encoding expert knowledge, assessing the system's usability, diagnostic performance, and impact in real-world settings. The findings based on the results, provide comprehensive insights into the efficacy and acceptance of the expert system.

4.2.1. Integration of Various Clinical Data Types

The integration of diverse clinical data types, including patient history, which significantly improved the accuracy of MSD diagnoses. The expert system's ability to synthesize and analyze comprehensive data sets allowed for more precise diagnostic outputs. This finding aligns with previous studies that emphasize the importance of multi-faceted data in enhancing diagnostic accuracy [21]. By utilizing a wide range of clinical inputs, the system was able to consider multiple diagnostic factors simultaneously, reducing the likelihood of misdiagnosis.

4.2.2. Encoding Expert Knowledge

The process of acquiring and encoding expert knowledge from experienced clinicians into the system's knowledge base proved effective in enhancing diagnostic capabilities. The expert knowledge, represented through if-then rules and decision trees, allowed the system to emulate human diagnostic reasoning accurately. This approach ensured that the system's recommendations were based on tried-and-true clinical expertise, which is crucial for maintaining high diagnostic standards [22].

4.2.3. Accuracy of the Expert System

The expert system, which integrated clinical knowledge, patient data, and diagnostic criteria, demonstrated high precision in diagnosing MSDs. The system's diagnostic accuracy was evaluated through extensive testing against established clinical benchmarks and expert opinions, showing that it could reliably identify and classify various musculoskeletal conditions. This high level of accuracy underscores the potential of expert systems to supplement and enhance human diagnostic efforts in clinical settings [23].

4.2.4. Usability and Acceptance by Healthcare Providers

User testing and feedback indicated that healthcare providers found the expert system highly usable and valuable for diagnosing MSDs. The system's interface was designed to be intuitive, and its recommendations were presented clearly and concisely, facilitating ease of use. Positive feedback from healthcare providers highlighted the system's potential to streamline the diagnostic process and support clinical decision-making, which is essential for its widespread adoption [24].

4.2.5. Diagnostic Performance

The diagnostic performance of the expert system met or exceeded clinical standards and expert opinions in terms of sensitivity, specificity, and reliability. The system's ability to accurately identify true positives (sensitivity) and true negatives (specificity) was comparable to that of experienced clinicians. This finding demonstrates the system's robustness and reliability as a diagnostic tool, capable of maintaining high performance across diverse clinical scenarios [25].

4.2.6. Real-World Implementation

Implementing the clinically validated expert system in real-world settings led to improved diagnostic outcomes, better patient management, and more efficient use of healthcare resources. The system facilitated early and accurate diagnosis, enabling timely interventions that improved patient prognoses. Additionally, by reducing diagnostic time and errors, the system contributed to more efficient healthcare delivery, highlighting its practical benefits in clinical practice [26].

5. Conclusion

In conclusion, the findings from this study affirm the significant potential of an expert system for diagnosing musculoskeletal diseases. By integrating diverse clinical data, encoding expert knowledge, and ensuring usability, the system demonstrated high accuracy, reliability, and acceptance among healthcare providers. Its implementation in real-world settings highlighted substantial improvements in diagnostic outcomes and healthcare efficiency. These results contribute to the growing body of evidence supporting the use of artificial intelligence in medical diagnostics, paving the way for further advancements in this field.

Musculoskeletal disease diagnosis system represents a significant advancement in healthcare technology, offering a valuable tool to aid healthcare workers in making timely and accurate predictions for a range of musculoskeletal diseases. By harnessing the power of artificial intelligence and expert systems, the system enables healthcare professionals to efficiently analyze symptoms and medical data, leading to near-accurate diagnoses within a short period.

One of the key benefits of the system is its ability to streamline the diagnostic process, allowing healthcare workers to quickly assess patients' conditions and provide appropriate treatment plans. This can be especially crucial in situations where rapid intervention is necessary to prevent further complications or alleviate symptoms.

Moreover, the expert system plays a vital role in data management by storing relevant information about diseases for future reference. This ensures that healthcare workers have access to a comprehensive database of medical knowledge, facilitating ongoing research and analysis in the field of musculoskeletal disease. By maintaining a repository of past diagnoses and treatment outcomes, the system enables continuous learning and improvement in diagnostic accuracy over time.

The development and implementation of an expert system for the diagnosis of musculoskeletal diseases represent a significant step forward in modern healthcare technology. By harnessing the power of artificial intelligence and expert knowledge, this system provides healthcare professionals with a valuable tool to assist in the accurate and timely diagnosis of musculoskeletal conditions.

The expert system offers several key benefits, including the ability to streamline the diagnostic process, improve diagnostic accuracy, and provide valuable insights into patient care. Through the integration of advanced algorithms and medical expertise, the system enables healthcare professionals to quickly analyze symptoms, medical history, and diagnostic tests to arrive at a precise diagnosis.

Furthermore, the expert system enhances patient care by facilitating faster treatment decisions and ensuring that patients receive appropriate interventions in a timely manner. By automating certain aspects of the diagnostic process and providing clinicians with real-time guidance, the system helps to optimize healthcare delivery and improve patient outcomes.

The expert system for the diagnosis of musculoskeletal diseases represents a significant advancement in healthcare technology, offering a powerful tool to support healthcare professionals in their clinical decision-making process. With its ability to enhance diagnostic accuracy, streamline workflow, and improve patient care, the Expert System holds great promise of revolutionizing the field of musculoskeletal medicine and improves the life of patients around the world.

Again, the muscle skeletal disorder diagnosis system represents a significant advancement in healthcare technology, offering a powerful tool to support healthcare workers in diagnosing and managing musculoskeletal conditions effectively. With its ability to provide near-accurate predictions and store valuable data for future reference, the expert system holds great promise for improving patient outcomes and advancing medical knowledge in the field.

6. Future Work

Future research efforts should prioritize the enhancement of user authentication, data security, retrieval, scalability, more accuracy, usability, exploration of integrated telemedicine, wearable devices and reporting functionalities to ensure the effectiveness, reliability, and security of expert systems in healthcare settings. By addressing these areas of improvement, future expert systems can better support healthcare professionals in delivering high-quality care while maintaining patient privacy and confidentiality.

Abbreviations

MSD(s)	Musculoskeletal Diseases
YLD(s)	Years Lived with Disability
WHO	World Health Organization

Author Contributions

Sunny Kalu Egereonu: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Resources, Visualization, Writing – original draft

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Chukwuemeka Etus: Project administration, Resources, Supervision, Writing – review & editing

Emmanuel Chukwudi Amadi: Supervision, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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