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Research paper

Iraq's Major Infectious Disease Diagnosis Using A Fuzzy Rule-Based System

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Abstract

The World Health Organization (WHO) declared that over 15 million people die annually due to infectious diseases at an average of 50,000 deaths per day. In the past two centuries, about 30 new cases have emerged and are threatening the health of millions of people currently. For most of these diseases, there is no available treatment strategy or vaccine currently. The WHO report warned that some of the major infectious diseases such as malaria, cholera, and hepatitis are a challenge in several countries despite the concerted efforts on their prevention and treatment. In this work, a fuzzy rule-based system was designed for the diagnosing of some major existing infectious diseases in Iraq and described the ways of detecting new ones. Diagnosis is often based on the symptoms that can be seen or felt. The medical advising system helps physicians or experts to make an appropriate disease diagnosis. Infection diseases have several symptoms and some of these symptoms are similar, thereby, creating several difficulties for accurate decision or diagnosis. In this study, the knowledge used was acquired through expert interviews and presented by the production rule (IF-THEN method). Fuzzy logic has been proven as a great tool for building intelligent decision-making knowledge-based systems and expert feedback. The results achieved in this study indicated a promising diagnosis performance of the system as it achieved 85.7% F-Score and 82.3% accuracy. This system will help in saving many lives in the rural communities where health care centers and expert physicians are limited.

Keywords: *Expert System, Knowledge Base, Diseases & Symptoms, Medical Diagnosis, Rule-based System.*

1. Introduction

Until the end of the 1970s, the major indicators of the health situation of the Iraqi people were improving significantly; health care services were fulfilling high criterion; but, this did not last long as the health system suffered from progressive negligence by the government that ruled Iraq before 2003, leading to a decline in the health indicators to low levels [1]. Many skilled health workers have left the country, while the young graduates keep emigrating. Despite the rebuilding efforts currently ongoing, the initial status of the health infrastructures is yet to be fully restored.

Consequent to this weakness in the health sector, many infectious diseases have emerged over time. According to the records of the Iraqi Ministry of Health, the emergence of infectious diseases like typhoid fever (TF), acute respiratory infection (ARI), hepatitis, malaria, leishmaniasis, and cholera has increased significantly since 1990. The survival of acute infectious diseases demands a better and efficient healthcare service delivery, such as the presence of a fast and reliable diagnostic system and an efficient e-Health system [2].

Artificial Intelligence (AI) is an aspect of computer science that deals with symbolic reasoning and problem-solving [3]. Expert systems (ES) as a branch of AI, are considered as software that simulates the behavior of a human expert [4]. The major aim of the ES is to provide knowledge and expert advice in specialized conditions [5]. Medical knowledge base (KB) is essential for building a medical advice system [6].

This paper focused on the design and development of a fuzzy rule-based ES (FRS) for the diagnosis of infectious diseases. The process of diagnosing infectious diseases through this program is not easy, but with the cooperation of both the physicians, patients, and the computer, things will work efficiently, accurately, and fast.

1.1. Iraq's Infection Diseases

Presently, Iraq is experiencing a double disease burden. The non-infectious diseases such as heart diseases and cancer account for most deaths in Iraq, but the infectious diseases account for the major causes of morbidity and mortality. According to the Iraqi Ministry of Health, diseases such as typhoid, viral hepatitis, malaria, and cholera are one of the most common infectious diseases in the country [1].

Hepatitis A. This is a liver disease caused by the Hepatitis A Virus (HAV)". It spreads through the consumption of water or food polluted with fecal matter. The disease is closely related to water or unsafe food, poor hygiene, especially in areas of poor sanitation. Roughly, people recover from hepatitis A with complete lifetime immunity; however, very few people with hepatitis A can die of hepatitis. Patients exhibit fever, fatigue, jaundice, loss of appetite, dark urine, abdominal pain, diarrhea and joint pain. The incubation period of Hepatitis A is about 15 to 50 days, with an average of 28 days. About 15% of patients suffer from symptoms lasting 6 months or longer. A safe and effective vaccine is available to prevent hepatitis A [7, 8].

Typhoid Fever. This is a life-threatening infection caused by the gram-negative bacteria Salmonella typhi. It is usually spread through ingestion of water or food contaminated by fecal matter or sewage. This condition is diagnosed by a sustained high fever, along with a headache, weakness, stomach pains, loss of appetite, early stage nonproductive cough, and rose-colored patches on the trunk (found in about 25% of light-skinned sufferers). Once infected with S. typhi, the bacteria spread and multiply within the bloodstream. Typhoid fever can be treated with antibiotics, and an effective vaccine is also available [7, 9].

Malaria. This is another life-threatening disease caused by an infection with the single-cell parasitic protozoa Plasmodium. It is transmitted to humans via the bite of the female Anopheles mosquito. The parasites multiply in the liver, attacking red blood cells. The symptoms usually appear within 10–15 days after the infective mosquito bite. This disease commonly presents with fever, chills, headache, nausea, vomiting, and malaise associated with anemia. In 2016, there were an estimated 200 million cases of malaria in 91 countries [7, 10].

Cholera. This is an acute diarrheal infection caused by the ingestion of water or food contaminated with the bacterium Vibrio cholera. The symptoms of cholera appear from two hours after exposure and may last up to five days. The symptoms range from mild to acute and usually presents with severe acute watery diarrhea lasting a few days. Vomiting and muscle cramps may also be experienced. This may lead to cold skin, sunken eyes, reduced skin elasticity, and wrinkles of the hands and feet. Skin discoloration may occur due to dehydration (skin turns blue). Cholera remains an international public health threat that portrays inequality and lack of social development. Studies have estimated a yearly approximate of 1-4 million cases of cholera and an estimated 80,000 deaths due to cholera globally [1, 7, 11].

A fast and accurate diagnosis of infectious diseases is integral to the suitable treatment of the affected individuals and in preventing the further spread of the infection. The FRS developed in this study offers opportunities to patients in developing countries to recognize when they have infectious diseases and seek solutions in the comfort of their homes. Table 1 shows the symptoms and treatments of these diseases according to the WHO (ICD-11 Beta Draft (Mortality and Morbidity Statistics) and fact sheets.

Table 1: Major Infectious Diseases, Their Symptoms, and Treatments [7]

Name of Infectious Disease	Symptoms	Treatment
Hepatitis A	Fever, malaise, dark-colored urine, loss of appetite, diarrhea, nausea, jaundice, Abdominal discomfort.	The treatment aims to maintain rest and sufficient nutritional balance, as well as the replacement of fluids lost to vomiting and diarrhea.
Typhoid fever	Acute fever, weakness, stomach pains, headache, Loss of appetite, flat rose-colored spots.	Taking the drugs prescribed by the physician; maintaining personal hygiene after visiting the restroom; avoid preparing food for others; check for the treatment progress with the doctor to ensure no bacteria is in the body.
Malaria	Fever, chills, headache, Nausea, vomiting, malaise.	The WHO recommended the artemisinin-based combination therapies (ACTs) for treating uncomplicated malaria. The ACT is a combination of 2 active agents with different action mechanisms. It is the most effective antimalarial medicines currently available. The recommended dosage against *P. falciparum* malaria is 5 ACTs. The therapeutic efficacy of ACTs against local *P. falciparum* strains should guide their choice for malaria treatment.
Cholera	Acute watery diarrhea, fever, nausea, toxemia, tenesmus, vomiting, muscle cramps.	Cholera can be treated easily using instant oral rehydration solution (ORS). The WHO / UNICEF standard ORS bag is reconstituted in 1 L of clean water. About 6 L is required daily to manage adult patients with moderate dehydration.

2. Related Work

- Olugbenga et al introduced a malaria expert system agent based on the rule-based system. They opined that the knowledge of the important rules on the causative agents of malaria (environmental and climatic agents) can support multiple malaria transmission cases. The results of the system showed that it is possible to control and reduce the spread of malaria following an environmental diagnostic approach. It also showed the future possibility of applying different AI subfields to various studies on infectious diseases. The system was developed using the Java Expert System Shell, Netbeans and SQL Server [12].
- Fatumo et al designed a diagnostic ES called XpertMalTyph for the diagnosis of different types of typhoid and malaria complications. The ES simulates the skills of the medical expert in disease diagnosis using computers. Hence, the ES can provide similar services in the absence of an expert, making it possible to treat patients even from their homes. They suggest the implementation of the ES with artificial neural networks (ANN). The XpertMalTyph was executed in Java Expert System Shell [13].
- Sunday et al designed and implemented e-Diagnosis as a rule-based ES for the diagnosis of all types of fever. The KB was developed using a rule-based system technique (a collection of the IF-THEN rules) extracted from an expert in the medical field in Nigeria. The application was developed in VB.Net for making a deduction of new facts from rules in the knowledge base. The advantages of the system include congestion reduction at the hospitals by providing diagnosis and solution for patients, cost reduction, accuracy and reliability of results [14].
- Samuel et al introduced a Web-Based Decision Support System (WBDSS) coupled with fuzzy logic (FL) for typhoid fever (TF) diagnosis. The KB of the system contained a fuzzy inference system (FIS). The system was developed to aid in the provision of accurate and timely TF diagnosis. Studies on the proposed system were performed based on the medical records of TF patients. The efficiency of the proposed system was based on the standard statistical metrics, while the achieved results showed a 94% efficiency of the system in providing an accurate diagnosis. The authors suggested the integration of ANN into the FL-based medical diagnosis systems for better performances [15].
- Ibrahim et al designed and developed medical expert systems for the diagnosis's and prescribing solutions to the treatment of hepatitis B virus. A feasibility study was executed through interviews with medical experts to extract expertise about hepatitis B. The merits of the system were summarized as fast diagnosis, error reduction, consistent, and accurate. The system provides sufficient solutions to the problems mentioned above [16].

3. FRS Medical Diagnosis System

The development of ES has gained theoretical and practical attention since the early 1980s, and the recorded progress and development demonstrates its great significance and value [17]. The ES provides solutions to many problems, especially in the management of patients' health. The system works by introducing a description of the problem (medical condition of the patient) and the proposed diagnosis via the user interface. The system searches the site library to determine the relevant information and proposed a solution. The selected information can either be accessed in full text or in synopsis format to help the evaluation of the solutions' suitability by the user. The inference engine recommends the appropriateness of a proposed solution to the user based on rules associated with the inference engine and the information entered through the user interface. The user can have an orderly or guided interaction with the inference engine. The structured mode is routed to inexperienced users and dynamically generates questions in response to the previous feedback from the user to enable the system to make a recommendation. The guided mode is mainly used by the experts as it provides a predefined questionnaire from which the user can identify the questions to be answered for a recommendation [18].

In building medical expert systems, the emphasis is often placed on the use of fuzzy theory and fuzzy logic as a methodology based on selected patient data and representation of medical knowledge and reasoning procedures. These methodologies contain several characteristics that suit them for modeling uncertain information on which medical principles are based, such as interpreting patient's condition, diagnostic and therapeutic decisions. Firstly, medical entities such as signs, symptoms, test results, diagnoses, diseases and treatment proposals can be defined as fuzzy sets. Consequently, the ambiguity inherent in these entities will be preserved. Secondly, FL provides the reasoning methods that can draw accurate and approximate conclusions [19]. The medical field uses the ES more than any other field. Many diagnostic and counseling programs have been developed to assist physicians either to diagnose a specific disease or to give first-aid/treatment advice to patients [17].

3.1. Rule-Based Systems (RBSs)

The rule-based systems are the simplest form of AI. In the RBSs, knowledge is presented in the form of production rules rather than in a declarative, static way as a set of things that are real. The RBS is defined based on the ES to be deployed [20]. The RB models are suited for domains that permit the presentation of knowledge in the form of thumb rules or heuristics. They are ideal for diagnostics and classification problems [21]. There are 2 advantages of the RBSs that made their development easy; i) with the clear definition of the expert's thinking, it is possible to predict how he thinks about the problem, ii) there is no need for a large training set in the system. On the other hand, the knowledge acquisition phase may be challenging [22].

3.2. Fuzzy Based Advice System

FL is a soft computing technique which has found application in the medical field due to its capability to handle information ambiguities, uncertainties, and contradictions. One major feature of the fuzzy rule system is that most of its rules are written in a language that can be easily understood by the experts instead of using computer language. This is a minimal level of communication between the knowledge engineer and the expert. Learning is a major advantage of the RBSs as it can be done through new rules establishment [22].

A fuzzy ES is a combination of rules and membership functions (MF) and this combination is mainly used for data reasoning. The fuzzy ESs tend to numerical processing; they receive numbers as inputs and translates them into linguistic terms like small, medium and large in a process called fuzzification. The rules are designed to assign these linguistic terms to similar terms related to the output. The fuzzy inference engine performs this task. Finally, the linguistic terms of the outputs are translated in a process called defuzzification. All the fuzzy rules and linguistic variables are stored in fuzzy KB. The fuzzy advice systems can handle imprecise information [23].

4. The Proposed System

There are different approaches and tools that can be used to develop FRS for the diagnosis and treatment of infectious diseases. The algorithms below illustrate the main steps of the proposed system. The architecture of the proposed Web-Based FRS is presented in Figure1. Figures 2 to 6 consecutively showed the execution of the proposed system.

Diagnosis Algorithm:

Input:
- User information (UID, Age, Location)
- Symptoms

Output:
- Diagnosis, disease, treatment, description
- Fuzzy diagnosis list (begin with the highest probability)

User-Information Interface:

Step 1:
- This serves as an introductory screen to the application where a user is expected to supply the username, age, and location to be saved as a record.

Step 2:
- Record sent to the database (DB) which is stored online in the cloud.

Symptoms Interface:

Step 1:
- Symptoms page allow the user to input the symptoms of the patient based on the complaint into the system.

Step 2:
- Fuzzy inference engine scans the rules in the knowledge base using forward chaining looking for a disease that matches with the data in the patient's query.

Step 3:
- If a rule is found, it is added to the working memory, followed by firing the rule and checking for new matches. This process is repeated until no match is found.

Step 4:
- Apply fuzzy logic to the firing rules.

Step 5:
- Map fuzzy inputs into their respective weighting factors to determine their degree of membership.

Step 6:
- Determine the evaluating rule base.

Step 7:
- Determine the firing strength of the rules.

Step 8:
- Sort the firing rules in a descending order according to their strength value using quick sort algorithm.

Diagnosis Interface:

Step 1:
- Displays the results of the fuzzy diagnosis list to the user.

Step 2:
- Output the description and the necessary drugs (treatment) for the disease with the highest fuzzy value.

Learner Algorithm:

Input:
- Symptoms List, Diagnosis Diseases List

Output:
- High-Performance System with Accurate Results,

Learn New Diagnosis Diseases
Step 1:
• If the submitted symptoms are not found in the KB and the system gives the right diagnosis, then, add it into the KB with the associated diagnosis and increase the score value +1 for the repeated symptoms.
Step 2:
• If the submitted symptoms are not found in the KB and the system gives a wrong diagnosis, then, add the right diagnosis and its associated symptoms into the KB.
Step 3:
• The expert can add new diseases.
Step 4:
• As a result, fuzzy logic inference will face problems of some diseases having the same symptoms. To solve this issue, the learner will give value for each symptom associated with that diagnosis and the score value will increase by 1 in each diagnosis for the same disease.

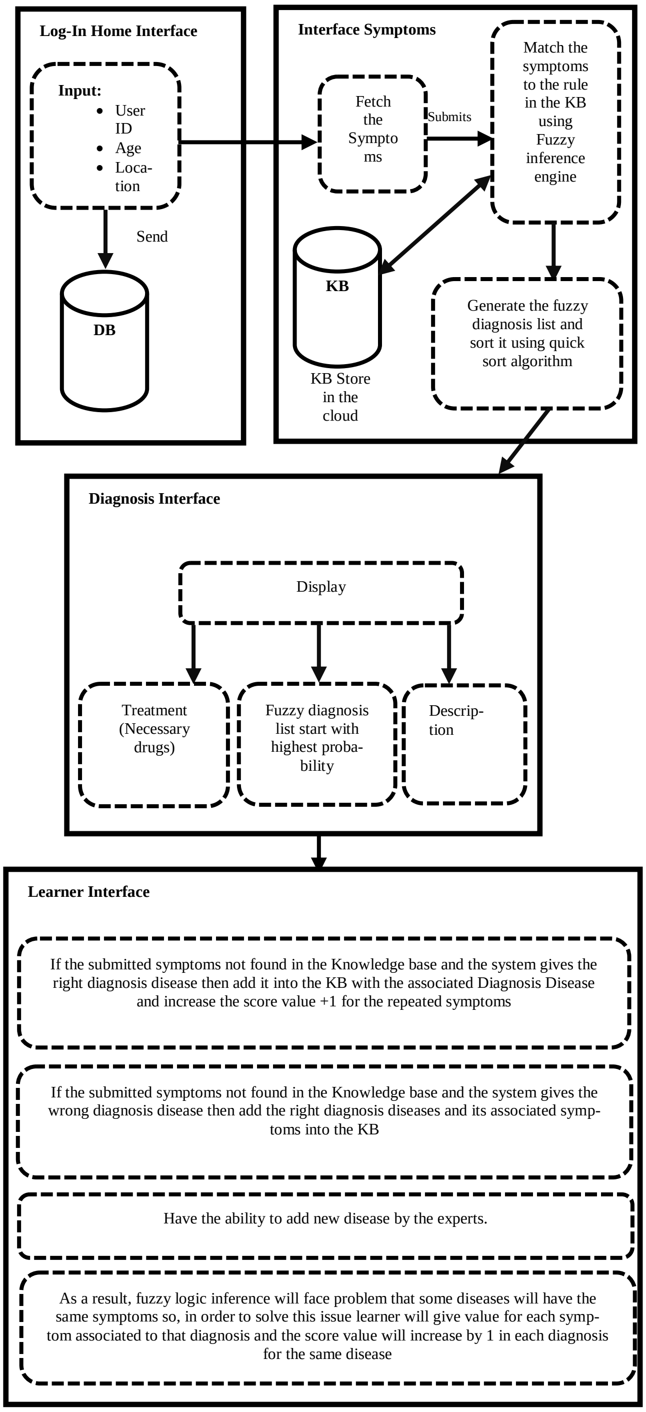

Fig. 1: FRS Architecture

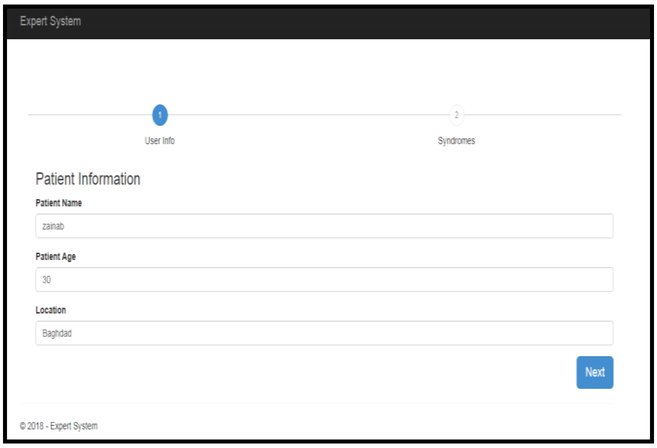

Fig. 2: User-Information Interface

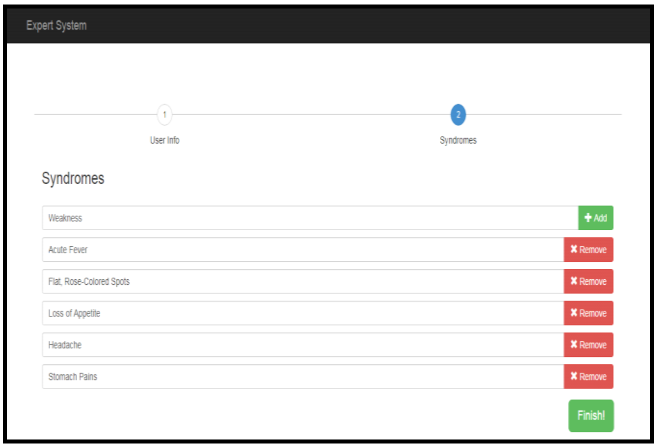

Fig. 3: Symptoms-Input Interface

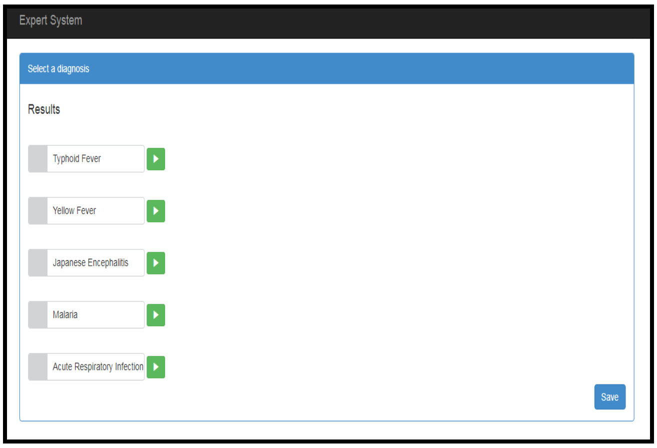

Fig. 4: Diagnosis-Result Interface

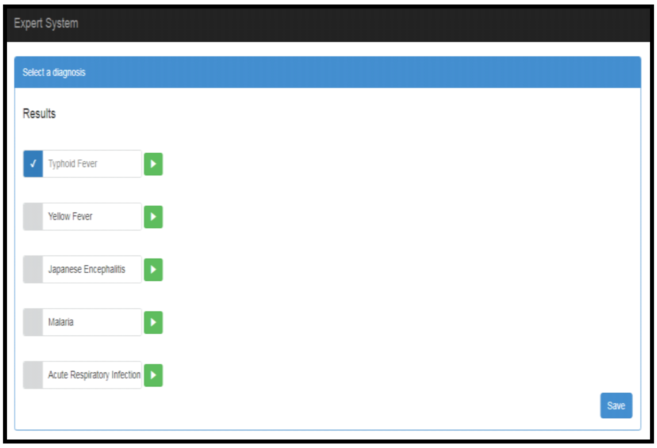

Fig. 5: Learner Interface (Choosing the right diagnosis if it's found in the list)

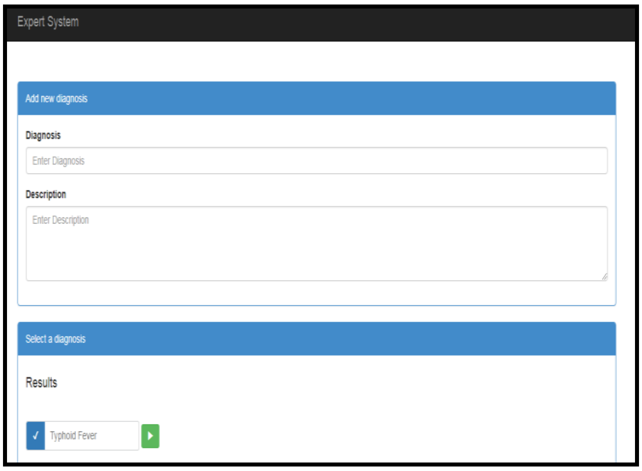

Fig. 6: Learner Interface (Entering the right diagnosis)

5. System Testing and Evaluation

The system was tested by a group of experts in the field of infectious diseases diagnosis and found to give a high performance and accurate results together with the ease of use. The performance of the FRS system was evaluated using a confusion matrix which contains the information on the actual case of the patient diagnosed by the expert and the diagnosis predicted by the FRS [24]. A two-class classifier confusion matrix is shown in Table 2 and the result is presented in Table 3.

Table 2: Two-Class Classifier Confusion Matrix

Confusion Matrix		Predicted	
		Negative	Positive
Actual	Negative	TN	FP
	Positive	FN	TP

The matrix inputs represent the followings:

- TN is the number of diagnosed cases (No, they don't have a disease) predicted correctly but they don't have the disease
- FP is the number of diagnosed cases (Yes, they do have a disease) predicted incorrectly but they do not have the disease
- FN is the number of diagnosed cases (No, they don't have a disease) predicted incorrectly and they do have the disease
- TP is the number of diagnosed cases (Yes, they do have a disease) predicted correctly and they do have the disease

Table 3: FRS Confusion Matrix

FRS Confusion Matrix		Predicted		
		Incorrect by the FRS	Correct by the FRS	Total
Actual	Incorrectly diagnosis cases	5	2	7
	Correctly diagnosis cases	1	9	10

The performance of the FRS was generally rated using the data in the matrix. Some metrics, including F- measure (F1 score), accuracy, precision, sensitivity (recall), and specificity were applied as the criteria to implement this test. Equations 1 to 5 show the formulas for these metrics:

$$F1-Score = 2 \times \frac{Precision \times Recall}{Precision + Recall} \quad (1)$$

$$Accuracy = \frac{TN+TP}{TN+FP+FN+TP} \times 100\% \quad (2)$$

$$Precision = \frac{TP}{TP+FP} \times 100\% \quad (3)$$

$$Recall = \frac{TP}{TP+FN} \times 100\% \quad (4)$$

$$Specificity = \frac{TN}{TN+FP} \times 100\% \quad (5)$$

Table 4: Accuracy of FRS

Results	
Accuracy	82.3%
Precision	81.8%
Sensitivity (Recall)	90%
Specificity	71.4%
F1-Score	0.857

The F1 score is the harmonic average of the precision and recall. The best value realized is one and the worst is zero [25]. As shown in Table 4, the F1 score of the FRS was 0.857 which indicates a very good performance.

6. Implementation Tools

A web-based FRS was designed and implemented to run under a WINDOWS 7 environment with Visual Studio 2017 platform. The system was developed using ASP.net programming language. The data was stored online in the cloud. Cloud computing is the provision of on-demand computing resources that use both the Internet and servers to maintain these resources. These resources include online computing, data storage space, backup, and data processing [26].

7. Conclusion

This paper presents the design of a fuzzy rule-based expert system (FRS) for the diagnosis of infectious diseases such as hepatitis, malaria, typhoid, and cholera. The design, called FRS, is a program developed in Visual Studio version 2017 using ASP.net as a programming language. The DB was stored online in the cloud. This design showed benefits of using a rule-based expert system for diagnosing patients. The merits of the system include a reduction in congestion at the hospitals, cost reduction, reliability, and accuracy of results. The developed FRS can learn the diagnosis of different diseases online. The achieved results indicate a promising diagnosis performance of the system as it achieved 85.7% F-Score and 82.3% accuracy.

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