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PAPER

Evaluation of a Prototype Mobile Application Based on Expert System for the Diagnosis of Diseases Transmitted by the Aedes Aegypti Mosquito

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ABSTRACT

The Aedes aegypti mosquito transmits the dengue, zika, and chikungunya viruses, endangering the health and lives of people in affected countries due to a lack of timely diagnosis. The objective of this study is to design and evaluate the feasibility of a mobile application based on an expert system for early diagnosis of diseases transmitted by the Aedes aegypti mosquito. The Buchanan methodology was used to develop the application. The results obtained show that the proposed mobile application has a diagnostic accuracy of 83%, a sensitivity of 91%, a specificity of 63%, and an error rate of 17%. The technical aspects of the application were also evaluated through a questionnaire administered to five computer experts. The results showed that the technical aspects of the application received an average rating of 3.91 out of a maximum of 5, with a standard deviation of 0.482. In addition, the usability of the application was evaluated using the standardized System Usability Scale (SUS), which was administered to a total of 15 users. The results of this evaluation showed that the application received an average score of 83 on the SUS scale, indicating a positive level of usability. In conclusion, the results support the effectiveness and potential of the application for the early diagnosis of diseases transmitted by the Aedes aegypti mosquito, providing a useful tool for the rapid detection of these diseases. Although it requires more attention to specificity and error rate to improve the accuracy of the diagnosis.

KEYWORDS

Aedes aegypti mosquito, chikungunya, dengue, expert system, mobile application, zika

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1 INTRODUCTION

The Aedes aegypti mosquito is the primary vector for the transmission of several viruses to humans. This mosquito is indigenous to Africa, yet it has spread to tropical and subtropical regions of the world. It is regarded as a crucial vector in the transmission of diseases like dengue, zika, chikungunya, and yellow fever [1] and is posing a serious threat to worldwide public health. These illnesses, primarily dengue, impact more than 100 tropical and subtropical nations in Asia, Africa, and the Americas. Approximately 400 million people around the world are affected by dengue, which has a negative impact on health systems. The problem is made worse by the absence of a particular medication and a ready-to-use vaccine [2]. Furthermore, in Europe, specifically in France, there were nine transmission events as of October 21, 2022, an unusual situation with 65 reported cases. This was more than the total number of cases recorded from 2010 to 2021. Six of these events occurred in regions where dengue had never been transmitted [3]. Like other countries, the Philippines has seen an upsurge in dengue cases, which has made the disease a significant public health concern [4].

On the other hand, Zika's emergence sparked a global alarm and is one of the viruses that is still actively spreading. In India, a laboratory-confirmed case of Zika was reported in the state of Kerala in July 2021, and the Zika outbreak in India began in 2017 [5]. Additionally, the emergence of Zika and chikungunya in the Americas has led to epidemics over the past decade, aggravating the challenges posed by dengue [6]. Uncontrolled population growth and urbanization with ineffective water management, are responsible for the spread of dengue [7]. Zika and chikungunya outbreaks stem from the same underlying issue.

Dengue, chikungunya, and other infections spread by the Aedes mosquito are among the most serious health issues in Peru. Especially dengue, due to the rise in cases and fatalities across the nation. In this context, climate change and other anthropogenic causes have made dengue illness a hazard for more than 50% of the Peruvian population [8]. Another problem that makes the disease difficult to treat is the fact that people who contract the disease self-medicate when they experience common symptoms such as fever and headache, which makes the sickness worse. In many situations, it happens because people are unaware of the symptoms caused by these diseases and lack access to a timely diagnosis. Additionally, the risk of mortality increases because of the late detection of diseases.

Given this problematic reality, it was considered extremely important to investigate an expert system based on mobile technology for the diagnosis of diseases transmitted by the Aedes mosquito. Since smartphones are becoming more common and used in many aspects of our daily lives, including in the health sector [9], these devices are especially useful in the self-diagnosis of health [10]. Furthermore, the use of software technologies in fields such as healthcare is growing daily, and the invention of new technologies, including smartphones, has made it possible for people to take care of their own health [11]. The mobile application allows immediate and real-time data management. It is a novel paradigm of medicine that has gained strength in the way medical care is delivered [12] and is a great tool to help control health. Likewise, the use of expert systems in mobile applications can also benefit users by reducing the amount of time and resources needed to find a solution to an issue.

Therefore, there is a need to evaluate the feasibility of a mobile application based on an expert system to address the problem of late detection of the disease caused by the Aedes aegypti mosquito.

The aim of the research is to design the prototype and evaluate the feasibility of the mobile application based on an expert system for the detection of diseases transmitted by the Aedes aegypti mosquito. Thus, to determine the feasibility of the mobile application as a tool for the early detection of diseases caused by the Aedes genus mosquito.

2 LITERATURE REVIEW

2.1 Situation of diseases caused by the Aedes aegypti mosquito in Peru

This section presents the situation of cases of diseases caused by the Aedes mosquito in Peru, such as dengue, zika, and chikungunya. Analysis and comparison are done on the number of reported cases, the incidence per 100 thousand inhabitants, and the number of deaths caused by these diseases in recent years.

Dengue. According to the report of the National Center for Epidemiology, Prevention, and Control of Diseases—the Ministry of Health (MINSA) on the weekly situation of dengue in Peru [13], up to week 14 of 2023, 4014 cases of dengue have been reported nationwide, accumulating a total of 41376 cases and 42 fatalities so far this year. The incidence was 122.29 per 100 thousand inhabitants. In 2022, in the same week, 22753 cases were reported and 42 deaths from dengue cases occurred, with an incidence of 68.44 per 100 thousand inhabitants. The difference in cases in 2023 compared to the previous year is 81.8%. In 2022, it was reported in the same week, with a difference of 49.1%. This indicates that in 2023, the cases will increase (see Table 1).

Likewise, according to the cases reported by departments, the department of Piura, located in the north of Peru and represented by the color navy blue, has more than 10,000 reported cases, followed by the Amazonian departments of Ucayali and Loreto, represented by the color emerald green, which have more than 5,000 cases. The departments that appear in white, which are five of the 24 departments, are those that do not register cases of dengue (see Figure 1).

Table 1. Cases, incidence, and deaths in Peru (2019–2023*)

Year	2019*	2020*	2021*	2022*	2023*
No. of Cases*	2733	14107	15261	22753	41376
Difference from the previous year (%)	0	416.2	8.2	49.1	81.8
Incidence per 100 thousand inhabitants	8.4	43.24	46.21	68.44	122.29
Deaths*	10	31	12	42	42

Note: *Dengue situation report up to week 14. Taken from the National Center for Disease Epidemiology, Prevention and Control—MINSA.

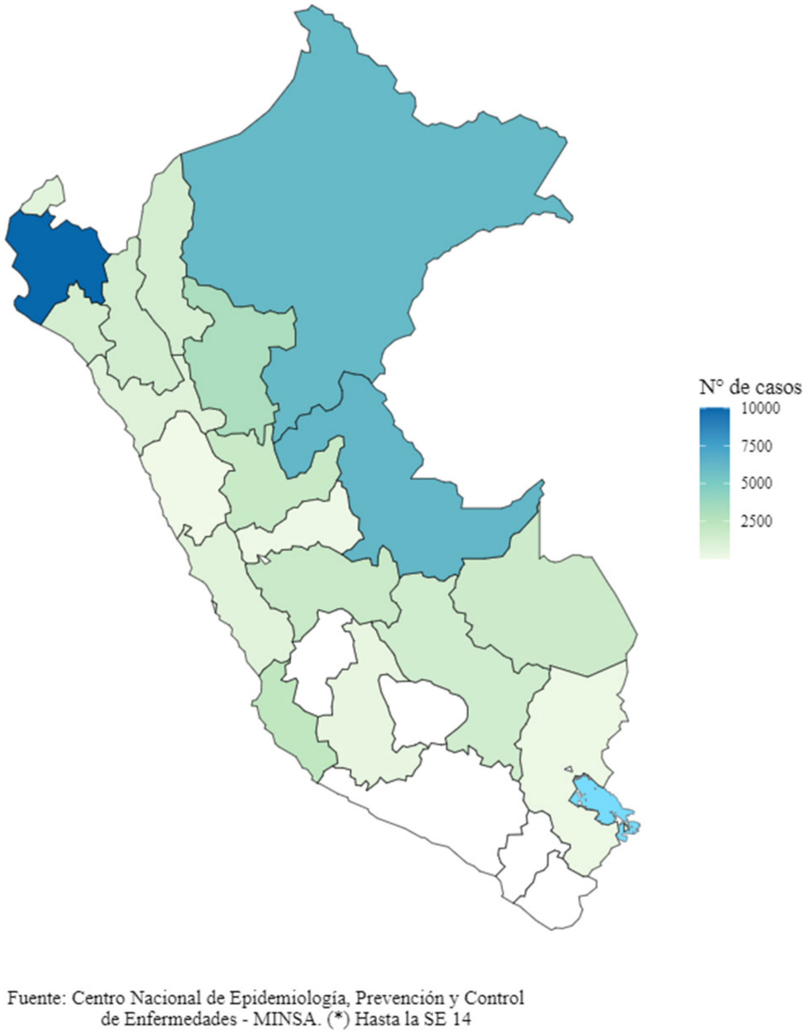

Fig. 1. Dengue cases by department, Peru 2023*. Dengue situation report (*) up to week 14

Zika. According to the report of the National Center for Epidemiology, Prevention, and Control of Diseases—MINSA on the weekly situation of zika in Peru [14], up to week 14 of 2023, 8 cases of zika have been reported nationwide, with an incidence rate of 0.024 per 100 thousand inhabitants. In the same way, no fatalities linked to the Peruvian zika outbreak have been reported since 2020. In addition, in 2022, during the same period, 8 cases were reported, with an incidence rate of 0.024 per 100 thousand inhabitants. Between 2020 and 2023, a greater number of cases were reported in 2020 during the same period, a total of 17 cases, with an incidence rate of 0.052 per 100 thousand inhabitants (see Table 2).

Table 2. Cases, incidence, and deaths due to zika in Peru (2020*–2023*)

Year	2020*	2021*	2022*	2023*
No. of Cases*	17	3	8	8
Incidence per 100 thousand inhabitants	0.052	0.006	0.024	0.024
Deaths*	0	0	0	0

Note: *Zika situation report up to week 14. Taken from the National Center for Disease Epidemiology, Prevention and Control—MINSA.

Chikungunya. According to the report of the National Center for Epidemiology, Prevention, and Control of Diseases—MINSA on the weekly situation of chikungunya in Peru [15], up to week 13 of 2023, 122 cases of chikungunya have been reported nationwide, with an incidence rate of 0.36 per 100 thousand inhabitants. Since 2019, there have been no recorded fatalities associated with the Peruvian chikungunya case. In addition, in 2021, in the same period, 151 cases were reported, with an incidence of 0.46 per 100 thousand inhabitants, the highest number of cases reported in the same period. Cases decreased to 84 in 2022 and then surged in 2023 (see Table 3).

Table 3. Cases, incidences and deaths due to chikungunya in Peru (2019*–2023*)

Year	2019*	2020*	2021*	2022*	2023*
No. of Cases*	29	50	151	84	122
Incidence per 100 thousand inhabitants	0.09	0.15	0.46	0.25	0.36
Deaths*	0	0	0	0	0

Note: *Chikungunya situation report up to week 13. Taken from the National Center for Disease Epidemiology, Prevention and Control—MINSA.

2.2 Related work

Thomas *et al.* [16] present the extension of a hybrid expert system, a system built on parallel coordinates and neural knowledge that can help with dengue illness diagnosis and severity assessment. The system's implementation consists of 140 rules that are used to categorize dengue infections. Finally, the hybrid expert system experiments were conducted using the technology acceptance model. They analyzed the system's utility and usability using this kind of model.

On the other hand, Khozaimi [17] focused on the design and implementation of a mobile application for the Android operating system called "Dengue Alert", based on multimedia support and with a range of text, image, and animation components. The purpose of the app is to educate users about dengue prevention and encourage them to put that knowledge into practice. Furthermore, they applied the certainty factor method to the mobile application to be able to anticipate. They were able to develop a mobile application as a result that enables the early detection of dengue hemorrhagic fever (DHF) and has a prediction accuracy of 97.6%.

de Araújo *et al.* [18], developed an expert system based on an android mobile app with the aim of assisting in the diagnosis of dengue, zika, and chikungunya infections. Additionally, one of its goals is to compare a patient's symptoms to a score that represents the likelihood that they have the disease at issue. The rule-based expert system was created in response to commonly reported symptoms. The results showed that, out of 96 tests, the expert system had a 96.88% accuracy rate. In addition, doctors from a public hospital also tested and achieved a success rate of 72.92%.

Likewise, they propose a belief-based expert system (BRBES) to perform chikungunya virus diagnosis in patients in the initial stages of infection by the virus [19]. Receiver operating characteristic (ROC) curves have been utilized to infer the existence of chikungunya, and the idea is also based on real data. They developed a perfect BRBES learning model for the various training set combinations to raise the assessment's accuracy. They also compared different deep learning and machine learning (ML) models. In this way, they show that the proposed model is an optimal learning model.

They also developed a workable approach for patients to self-diagnose themselves as well as a trustworthy model that enables the recognition of signs and symptoms in the initial stages of dengue infection [20]. To give patients a quick self-diagnosis of dengue, they developed the system using two techniques: fuzzy expert systems and data mining. The diagnostic rules were applied based on fuzzy logic from an interview with a doctor. Similarly, before applying the rules, their precision was tested by applying data mining. Finally, according to the results of the test, they obtained a positive result, demonstrating that the fuzzy logic applied with data mining has reliable precision for the self-diagnosis of patients on their own, thus identifying dengue fever in its initial stages.

In conclusion, the reviewed studies show a tendency to use a mix of techniques, including expert systems and machine learning. The evaluation of the precision and accuracy of these approaches is carried out by analyzing the correct classification of cases and the errors made in comparison with real cases. They also use different methods to evaluate the usability of the system. However, most of the reviewed studies only demonstrate expert systems that can identify only one type of disease. Therefore, the present study aims to fill this gap by developing a mobile application expert system that enables patients to self-diagnose diseases such as dengue, zika, and chikungunya.

3 MATERIALS AND METHODS

3.1 The mythology of expert system development

The development of the system in the research used the Buchanan methodology. A process that is based on the conventional waterfall life cycle for the creation of expert systems. The creation of the entire system is further separated into five phases, as shown in Figure 2: identification, conceptualization, formalization, implementation, and test.

3.2 Data collection technique and rule formulation

Information collection. Building an expert system to diagnose dengue, zika, and chikungunya requires accurate and reliable information from multiple sources. To do this, interviews are conducted with specialist physicians, and epidemiological data and symptoms are collected. Likewise, updated scientific studies and other reliable sources are reviewed. The combination of these sources of information will allow the development of a robust and reliable expert system for early and accurate diagnosis. In addition, an interview is carried out with experts who know the technical aspects and implications of diagnosing the disease with traditional methods. In this way, collect the information needed to have a broad vision of the technical part of the expert system and the diagnosis of diseases.

Formulation of rules. The rules are formalized according to the following scheme: IF (condition) THEN (consequent or conclusion) is supported by a decision tree. The construction of a rule-based expert system and decision tree combines logic and structure to make decisions. The rules establish conditions that guide the diagnosis, while the tree organizes the conditions and actions. This combination allows automated and efficient analysis, evaluation of conditions, and following the path in the tree for accurate and reliable disease diagnosis.

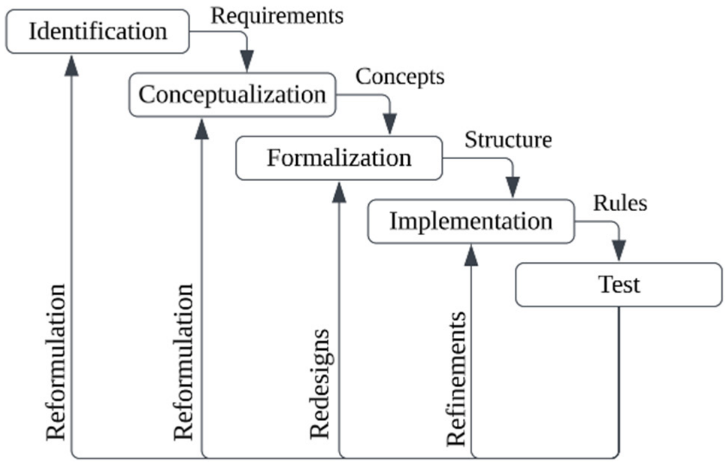

Fig. 2. Buchanan method phases

3.3 Evaluation and determination of the feasibility of the prototype

Prototype evaluation method. The evaluation of the prototype is done by means of a confusion matrix, which shows the number of true positives (TP), false positives (FP), true negatives (TN), and false negatives (FN) obtained by the expert system. From this matrix, the Accuracy (1), sensitivity (2), specificity (3), and error rate (4) of the system are calculated.

$$Accuracy = \frac{(TP+TN)}{(TP+FP+TN+FN)} \quad (1)$$

$$Sensitivity = \frac{TP}{(TP+FN)} \quad (2)$$

$$Specificity = \frac{TN}{(TN+FP)} \quad (3)$$

$$Error\,rate = \frac{(FP+FN)}{(TP+FP+TN+FN)} \quad (4)$$

Method of evaluation of technical aspects. Technical aspects of the system, such as performance, stability, and other items related to technical expertise, are evaluated. To determine the level of acceptance of these aspects, a specially designed survey or questionnaire is used to collect expert opinions on various technical aspects of the application. The mean and standard deviation (SD) are then calculated.

Usability evaluation method. For the evaluation of the usability of the application, the System Usability Scale (SUS) is used, a reliable and inexpensive tool that can be used to carry out general evaluations of the usability of systems [21]. A scale that consists of a standard questionnaire made up of 10 items that measure the user's perception of the ease of use and efficiency of the system.

4 CASE STUDY

Each phase of the Buchanan methodology is developed in this section.

4.1 Identification

Problem. The Aedes aegypti mosquito is the vector of several infectious diseases, including dengue, zika, and chikungunya, that affect the Peruvian population. These diseases have some common and different symptoms, but they are all caused by mosquito bites. Due to limited access to medical treatment in some areas of the country, some people may not be aware of the symptoms caused by these infectious diseases, and due to the lack of timely diagnosis to treat the disease, they risk aggravating the condition, which can even lead to death.

Solution. Given the problem, a mobile application-based expert system for the diagnosis of mosquito-borne disease is proposed, a system that can quickly recognize and classify infectious diseases such as dengue, zika, and chikungunya to offer fast and efficient treatment. By facilitating self-diagnosis for users, these diseases can be ruled out, and if they do get sick, they can be quickly treated thanks to early diagnosis.

Familiarization with the problem. To become familiar with the problem, interviews are conducted with human experts (infectologists), and other sources are reviewed, such as books, magazines, and articles that deal with the disease caused by the mosquito. In this way, an understanding of the subject is achieved since the expert system is focused on the diagnosis of the disease transmitted by the Aedes aegypti mosquito. The expert system's structure is also established when the essential data has been gathered through interviews or other sources of information.

Structure. The structure of the expert system is shown in Figure 3, where the user interface (mobile app) allows the user to interact with the expert system. When a patient exhibits symptoms such as fever or headache, for example, a diagnosis is made using a mobile application, with the patient's symptoms of the diseases being entered as data. The knowledge base (made of the factual foundation and rules) is meticulously organized and structured and contains the knowledge (symptoms) received from the expert and from the various information sources. The inference engine proceeds with the diagnosis to identify the probable disease based on the symptoms provided by the patient.

4.2 Conceptualization

From the data gathered, the qualitative information (symptoms and the associated disease) is categorized for use in the expert system's knowledge base representation. In this case, the qualitative information is classified with the information obtained from the official websites of the World Health Organization (WHO), the Pan American Health Organization (PAHO), the MINSA, and other reliable sources of information.

Three diseases that are spread by the Aedes vector were identified and are represented in Figure 4. These diseases are zika, dengue (dengue 1: mild or moderate; dengue 2: severe), and chikungunya, with their respective common symptoms. Likewise, a correlation was established between the symptoms and each potential disease, allowing for the identification of diseases that have a common set of symptoms.

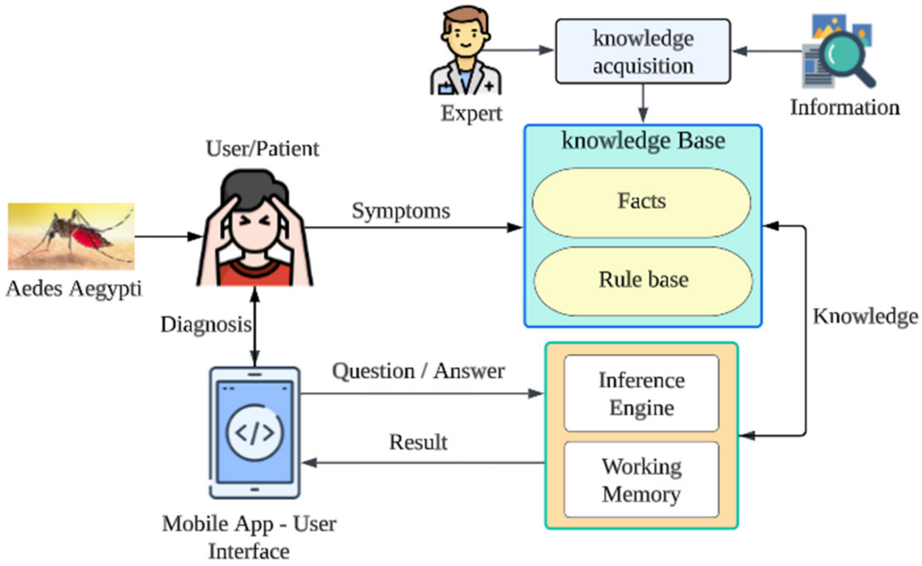

Fig. 3. Structure of the expert system

4.3 Formalization

Knowledge about the problem and the solution is expressed in a formal way. The knowledge base is designed to consist of sets of facts and applied rules [22]. In this sense, considering the components of the knowledge base, the facts are described and the rules for solving the problem are formulated.

Fact base. The information that corresponds to the problems that the expert system will employ to solve them is contained in the fact base, also known as working memory. This database only contains data pertaining to diseases. The specific symptoms presented by the patient make up the fact base, which consists of concrete knowledge (see Table 4).

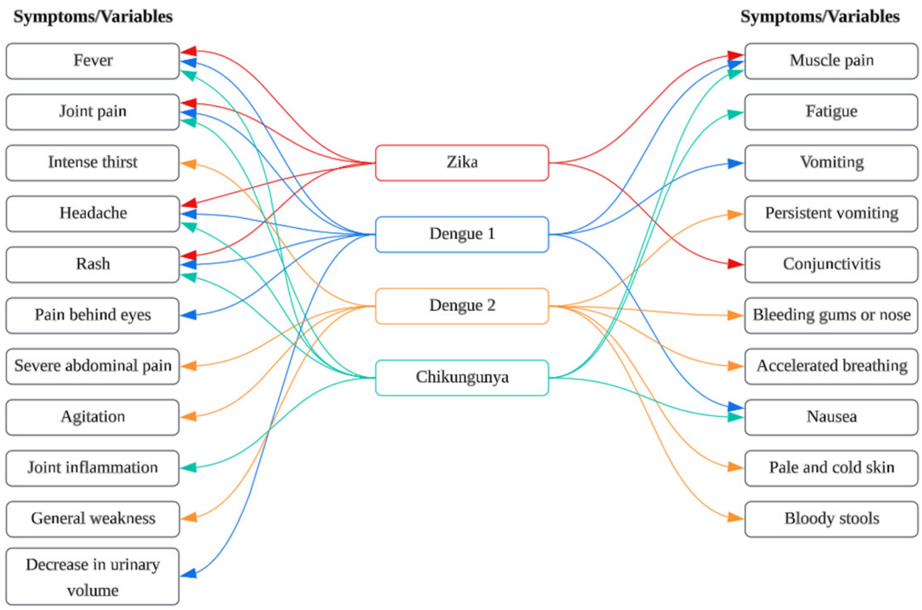

Fig. 4. Correlation between symptoms and potential disease

Table 4. Fact base

Number of Facts	Description	Disease
1	The patient has fever.	Zika, dengue 1 and chikungunya
2	The patient has joint pain.	Zika, dengue 1 and chikungunya
3	The patient is intensely thirsty.	Dengue 2
4	The patient has a headache.	Zika, dengue 1 and chikungunya
5	The patient has rashes.	Zika, dengue 1 and chikungunya
6	The patient has pain behind the eyes.	Dengue 1
7	The patient has severe abdominal pain.	Dengue 2
8	The patient is agitation.	Dengue 2
9	The patient has inflammation in the joints.	Chikungunya
10	The patient has general weakness.	Dengue 2
11	The patient has muscle pain.	Zika, dengue 1 and chikungunya
12	The patient has fatigue.	Chikungunya
13	The patient has vomiting.	Dengue 1
14	The patient has persistent vomiting.	Dengue 2
15	The patient has conjunctivitis.	Zika
16	The patient has bleeding from the gums or nose.	Dengue 2
17	The patient has rapid breathing.	Dengue 2
18	The patient has nausea.	Dengue 1 and chikungunya
19	The patient has pale and cold skin.	Dengue 2
20	The patient has bloody bundles.	Dengue 2
21	The patient has decreased urinary volume.	Dengue 1

Rule base. All the symptoms identified in the conceptualization phase are used as input variables for the expert system. These variables stand in for the cluster of zika, dengue, and chikungunya disease symptoms. The inference engine uses this information to solve the problem by simulating human knowledge. The inference engine is a mechanism that identifies and combines a set of rules to reach a conclusion based on the current problem information provided by the user [23]. The inference engine uses a rule base supported by a decision tree to draw conclusions. Figure 5 shows an example of two rules selected from a total of 150 formulated rules. On the other hand, Figure 6 shows an example of part of a decision tree built using all the symptoms identified for each of the diseases.

```
RULE 1:
        IF( fever="yes" AND joint_pain="yes" AND intense_thirst="no" AND headache="yes" AND
            rash="yes" AND pain_behind_eyes="yes" AND severe_abdominal_pain="no" AND agitation="no" AND
            joint_inflamation="no" AND general_weakness="no" AND decrease_urinary_volume="yes" AND
            muscle_pain="yes" AND fatigue="no" AND vomiting="yes" AND persistent_vomiting="no" AND
            conjuntivitis="no" AND bleeding_gums_nose="no" AND accelerated_breathing="no" AND
            nausea="yes" AND pale_cold_skin="no" AND bloody_stools="no"
        )THEN Diagnosis: You have Dengue 1 (mild or moderate)
RULE 2:
        IF( fever="yes" AND joint_pain="yes" AND intense_thirst="no" AND headache="yes" AND
            rash="yes" AND pain_behind_eyes="no" AND severe_abdominal_pain="no" AND agitation="no" AND
            joint_inflamation="no" AND general_weakness="no" AND decrease_urinary_volume="no" AND
            muscle_pain="yes" AND fatigue="no" AND vomiting="no" AND persistent_vomiting="no" AND
            conjuntivitis="no" AND bleeding_gums_nose="no" AND accelerated_breathing="no" AND
            nausea="no" AND pale_cold_skin="no" AND bloody_stools="no"
        )THEN Diagnosis: You have possible Zika, Dengue 1 (mild or moderate) or Chikungunya.
```

Fig. 5. Rule base for diagnosis

4.4 Implementation

The construction of the prototype of the system is carried out according to the flowchart defined for the development of the system (see Figure 7). During the design phase, the Figma platform, a visual design and prototyping tool [24], is used to design the user interface. The design is developed keeping in mind the tasks to be performed by the expert system, based on the identification of tasks and rules formulated for the system. In the functionality development phase, the application functions are developed and the knowledge base is implemented using specialized tools. Finally, unit and integration tests are performed before moving on to the system test and evaluation phases.

```
: Do you have a fever?
  - Yes: Next question
  - No: Diagnosis = No mosquito-borne disease.

: Do you have joint pain?
  - Yes: Do you have pain behind the eyes?
    - Yes: Diagnosis = You have Dengue 1 (mild or moderate).
    - No: Diagnosis = You have Chikungunya.
  - No: Next question

: Do you have a headache?
  - Yes: Do you have rashes?
    - Yes: Diagnosis = You have Zika.
    - No: Diagnosis = You have Dengue 1 (mild or moderate) or Chikungunya.
  - No: Diagnosis = You have Dengue 1 (mild or moderate) or Chikungunya.
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Fig. 6. Decision tree

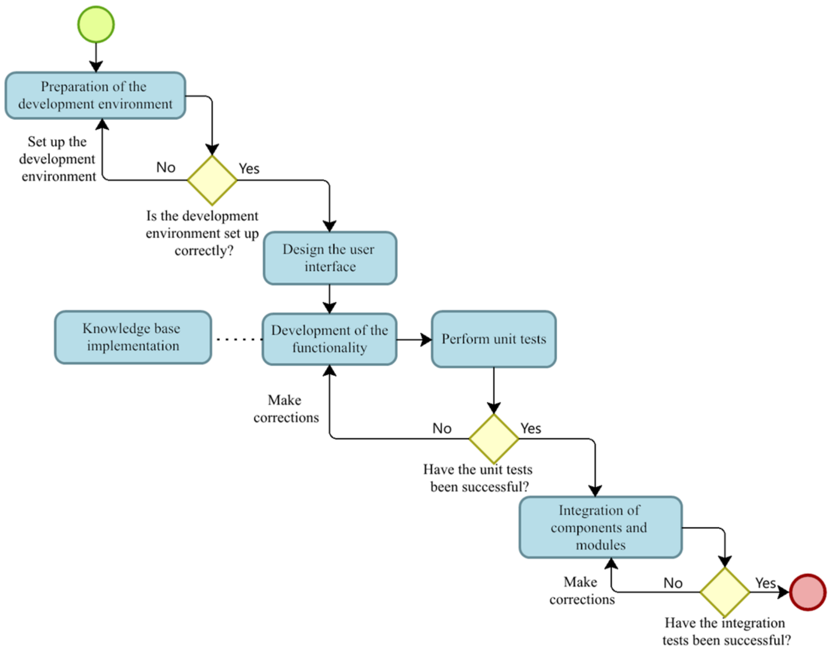


Fig. 7. Flowchart for the development of the proposed application

4.5 Test

In this phase, an evaluation of the diagnostic effectiveness of the prototype is performed using a confusion matrix, which allows us to analyze various key metrics such as accuracy, sensitivity, specificity, and error rate. In addition to evaluating the technical aspects of the application (see Table 5), usability is also evaluated using a predefined questionnaire using the SUS method (see Table 6).

Table 5. Technical aspects of the system which are the subject of the evaluation

#	Technical Aspects	Description
1	Consultation mechanisms	The system makes it easy for users to interact with specific queries or data requests.
2	Explanation and justification	The system is capable of explaining its conclusions and recommendations, providing a coherent justification based on the rules and applied knowledge.
3	Adaptability	The system is able to adapt to changes in the knowledge base or new rules without negatively affecting its functionality.
4	User interface	The interface is intuitive and friendly to facilitate communication and data entry.
5	Efficiency and performance	The speed and response capacity of the system are optimal to perform complex reasoning and deliver results in real time.
6	Treatment of uncertainty	Since the diagnosis may be uncertain in some cases, the system addresses this uncertainty and provides appropriate options.
7	Update mechanisms	The system is updated with new knowledge or changes in the domain.
8	Inference and reasoning	The system uses the knowledge base to perform the reasoning process and draw conclusions based on the information provided by the user.
9	User control and freedom	The system provides options for users to undo actions or exit tasks without losing their progress.
10	Ease of data entry	The data entry required for diagnosis is quick and easy to perform.
11	Feedback and confirmation	The system provides clear and appropriate feedback in response to user actions, for example, displaying error messages when necessary or confirming important actions to avoid errors.

Table 6. Predefined questionnaire of the SUS method

Id	Item
1	I think that I would like to use this system frequently.
2	I found the system unnecessarily complex.
3	I thought the system was easy to use.
4	I think that I would need the support of a technical person to be able to use this system.
5	I found the various functions in this system were well integrated.
6	I thought there was too much inconsistency in this system.
7	I would imagine that most people would learn to use this system very quickly.
8	I found the system very cumbersome to use.
9	I felt very confident using the system.
10	I needed to learn a lot of things before I could get going with this system.

5 RESULT

5.1 About the interview

A five-question interview was conducted with experts to better understand the technical part of building an expert system and the implications of traditional diagnosis, taking into account aspects of diagnosis, limitation, ethics, accessibility, and training. Figure 8 shows the analysis of the results obtained from the interviews using the ATLAS ti 22 software. According to the figure, from the diagnostic aspect, various difficulties associated with traditional diagnosis were identified. These include the lack of precision of existing methods, delays in laboratory analysis, and difficulties in distinguishing the symptoms of these diseases. In addition, regarding the limitations and difficulties in implementing an expert system based on mobile technology for diagnosing these diseases, the experts pointed out the difficulty in developing an accurate algorithm, adapting the system to mobile devices, and the need for Internet access. In terms of accessibility, experts point out that specific barriers are identified in rural areas, such as a lack of adequate telecommunications infrastructure, economic challenges in acquiring mobile devices, and language or cultural barriers that make it difficult to understand and use the system. In terms of training, the experts said that it is addressed through training in the management of the system as well as through technical support to help solve any problems that may arise. Similarly, in terms of ethical implications, experts stressed the importance of ensuring data security through security and encryption measures, as well as providing adequate information to patients about the processing of their data and protecting their privacy. They also point out that it is important to comply with the rules and standards that govern the protection of medical data. Analysis of the interviews revealed a number of key issues and considerations related to traditional diagnostics, the implementation of mobile technology-based expert systems, and the accessibility and ethical issues associated with such systems. These findings are important to guide the development and future implementation of diagnostic systems in the field of these diseases.

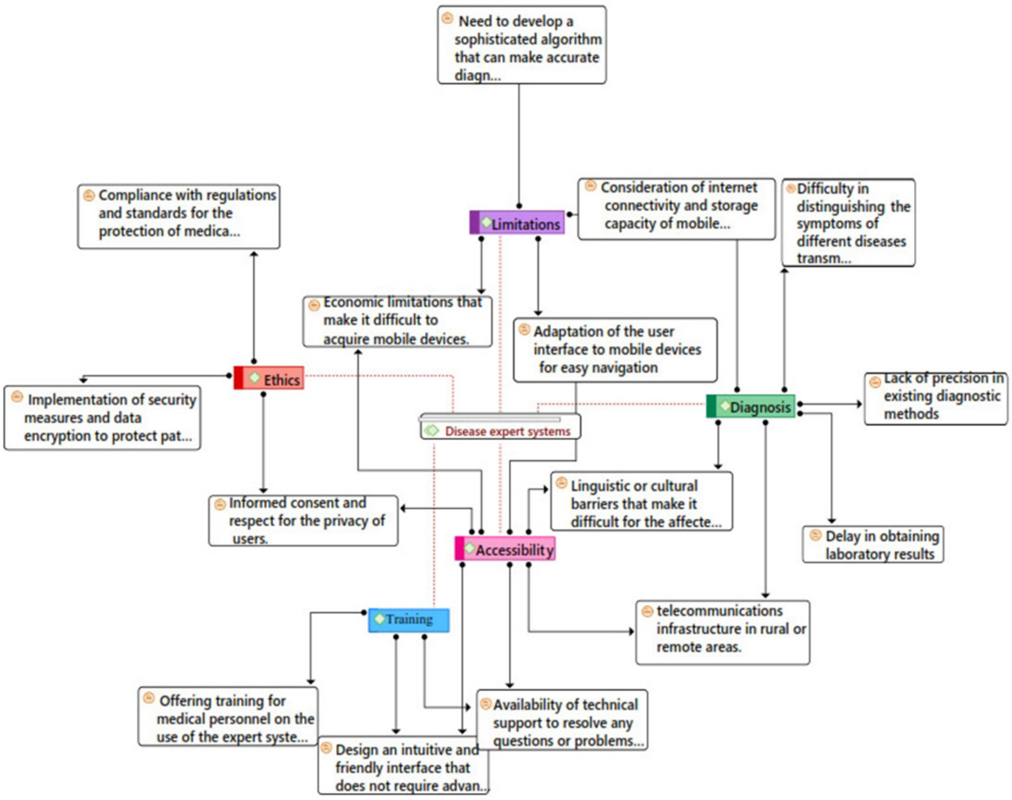
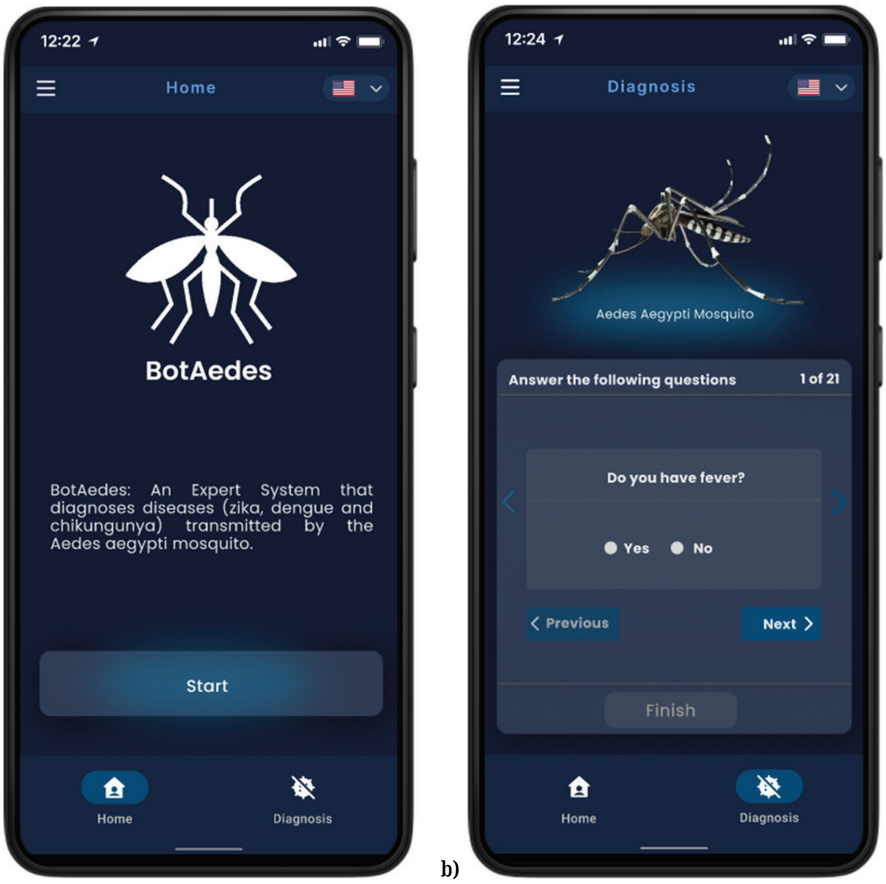


Fig. 8. Network diagram of the interview analysis

5.2 User interface

Figure 9(a) shows the home interface, which presents a brief description of the diseases that can be diagnosed with the application named BotAedes. Meanwhile, Figure 9(b) shows the diagnostic interface, where 21 questions related to the symptoms of dengue, zika, and chikungunya are presented. The patient must answer if he has these symptoms or not. At the end of the questions, the system infers the type of disease that the patient presents based on the answers provided.

On the other hand, Figure 10 presents the diagnostic results interface, where the possible diagnosed disease, the corresponding conclusion, and the recommendations based on said diagnosis are displayed. In addition, three options are offered anchored to the official websites of the entities in charge of the health field: MINSA, PAHO, and WHO, where they provide general information about the disease in question. This makes it easy for the user to enter if they want to search for additional information.



a) b)

Fig. 9. Mobile application: (a) Home interface and (b) Diagnostic interface

5.3 Testing and evaluation of the prototype

Testing of system effectiveness. After carrying out an evaluation using a confusion matrix with 30 tests, the effectiveness results of the expert system for the early diagnosis of dengue, zika, and chikungunya were obtained. With an accuracy of 83.33%, the system shows reasonably high accuracy in its diagnoses overall. In addition, with a sensitivity of 91%, the system demonstrates a good capacity to detect positive cases of the evaluated diseases. However, the specificity of the system is 63%, which suggests that there is a considerable percentage of false positives, that is, negative cases wrongly classified as positives. On the other hand, the error rate of 17% indicates the proportion of incorrect diagnoses made by the system. Although the system has a high capacity to detect positive cases, attention must be paid to its specificity and error rate to improve accuracy and reduce false positives (see Table 7).

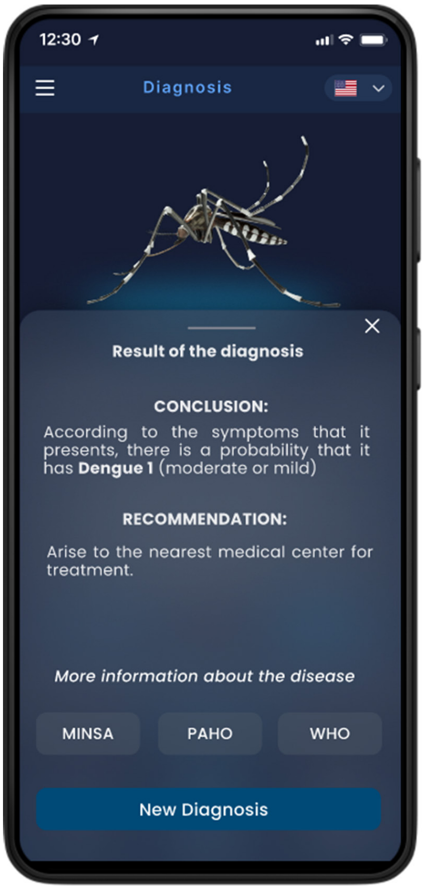


Fig. 10. Mobile application: Result interface

Table 7. Test result

Metrics	Result
Accuracy	83%
Sensitivity	91%
Specificity	63%
Error rate	17%

Evaluation of acceptance of technical aspects. Table 8 shows the evaluation of the technical aspects of the system by five experts. Each expert evaluated each aspect on a scale from 1 to 5 in a questionnaire defined with 11 aspects to be evaluated, where 1 indicates that the technical aspect evaluated is deficient and 5 indicates excellent. After analyzing the results with the SPSS Statistics software, a total average of 3.91 was obtained, with a standard deviation of 0.482. This total average indicates that the technical aspects of the system are acceptable since it exceeds the minimum acceptable average of 3.5 on a scale of 1 to 5, where 5 is the maximum acceptance. The standard deviation indicates the variability of the experts' responses, and in this case, a relatively low standard deviation indicates that the experts' opinions are closer to the overall average. In general, these results indicate that the technical aspects of the expert system in the mobile application are well received and meet the minimum acceptance standards.

Table 8. The results of the evaluation of the technical aspects

Technical Aspects	Experts					Average	SD
	1	2	3	4	5		
Consultation mechanisms	4	4	4	4	4	4.00	.000
Explanation and justification	4	4	3	4	3	3.60	.548
Adaptability	4	4	3	3	4	3.60	.548
User interface	5	5	5	4	5	4.80	.447
Efficiency and performance	4	4	4	4	4	4.00	.000
Treatment of uncertainty	4	3	4	4	4	3.80	.447
Update mechanisms	4	3	4	3	4	3.60	.548
Inference and reasoning	4	4	3	3	4	3.60	.548
User control and freedom	4	3	4	4	4	3.80	.447
Ease of data entry	4	4	4	4	4	4.00	.000
Feedback and confirmation	4	4	4	4	4	4.00	.000
Total						3.91	.482

Usability evaluation. An evaluation of the usability of the BotAedes application was carried out, in which 15 users participated. Each user rated each item on a scale from 1 to 5, where 1 represents strongly disagreeing and 5 represents strongly agreeing. The SUS method was used. The results are shown in Table 9. Most of the users obtained total scores between 80.8 and 84.0, corresponding to the category Grade A and in a percentile range of 90 to 95. Only a few scored between 84.1 and 100 in the Grade A+ category and in the 96 to 100 percentile range. Very few were in the Grade B+ and A- categories with scores between 77.2–78.8 and 78.9–80.7 and in percentile ranges between 80–84 and 85–89, respectively, according to the Sauro-Lewis curved rating scale for SUS scores [25]. In addition, the average rating was 83, indicating good usability, considering that the average acceptable score is 68 out of 100. These results suggest that the majority of the evaluated users found the mobile application easy to use and efficient, thus meeting their usability expectations.

Table 9. SUS questionnaire results

Id	Sample/Users														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1	4	4	3	4	3	4	4	3	4	4	3	4	4	3	3
2	2	2	2	1	2	2	2	2	2	2	3	2	1	2	2
3	4	5	4	4	5	5	5	5	5	4	5	5	5	5	5
4	1	1	2	1	1	2	1	1	1	1	2	2	1	1	1
5	4	4	4	5	4	4	5	5	4	4	5	4	4	4	5
6	2	1	2	2	2	2	2	2	1	2	2	2	2	2	2
7	4	5	4	4	5	5	4	4	5	4	5	4	4	5	5
8	1	1	1	1	2	2	1	2	1	2	1	1	1	1	1
9	4	4	4	3	4	4	3	3	4	4	3	4	4	4	3
10	1	2	1	2	1	2	2	1	1	1	2	1	1	1	1
Total score	83	88	78	83	83	80	83	80	90	80	78	83	88	85	85

6 DISCUSSION

The implementation of rule-based expert systems for the diagnosis of diseases such as dengue, zika, and chikungunya has shown promise in several studies. In this research, we developed a mobile application expert system with 150 rules supported by a decision tree, which showed positive results in terms of diagnostic accuracy, sensitivity, specificity, and error rate. The proposed system showed a diagnostic accuracy of 83%, a sensitivity of 91%, a specificity of 63%, and an error rate of 17% in the tests performed with a set of 30 cases. These results indicate that the system was able to correctly identify a high percentage of positive cases, although some false positives and negatives occurred. Comparing the results with those of other researchers [18], who also implemented a rule-based expert system to diagnose dengue and zika, we found that their system had a success rate of 96.88% in a set of 96 tests (32 for each disease). These results suggest that their expert system was able to effectively associate the cases analyzed with others found in the literature, demonstrating a high diagnostic capacity. In addition, researchers [16] presented an innovative approach by implementing a hybrid expert system based on neural insight and parallel coordinate visualization for the diagnosis and severity assessment of dengue. Their system, comprising 140 classification rules, was evaluated using a technology acceptance model that analyzes the usefulness and usability of the system. However, the study did not provide quantitative performance data. Overall, these studies demonstrate the potential of rule-based expert systems for diagnosing diseases such as dengue, zika, and chikungunya. Nevertheless, it is important to emphasize that challenges remain in improving accuracy and reducing diagnostic errors.

7 CONCLUSION AND SCOPE FOR FURTHER RESEARCH

The study shows that the development and evaluation of a mobile application based on an expert system for the early diagnosis of diseases transmitted by the

Aedes aegypti mosquito is feasible and promising. The application shows high diagnostic accuracy, with 83% accuracy and 91% sensitivity. However, more attention needs to be paid to specificity and error rate to improve diagnostic accuracy. In addition, the technical aspects of the application were positively evaluated by computer experts. The usability of the application was also highlighted, with an average score of 83 on the SUS scale. These results suggest that the application has the potential to improve the early detection of mosquito-borne diseases, which could have a significant impact on the prevention and timely treatment of such diseases, thus protecting the health of those affected.

For future research, it is suggested to consider the implementation of more advanced AI techniques, such as machine learning, to achieve greater precision and generalization in the diagnosis of these diseases. It is also recommended to evaluate expert systems using large samples to obtain accurate results. In addition, the technical aspects and usability of the application should be evaluated with the participation of experts and users from a large sample to obtain a wide range of opinions and comments.

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