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by Zilvanhisna Emka Fitri

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Combination of forward chaining and certainty factor methods for the early detection of Acute Respiratory Infections (ARI)

Zilvanhisna Emka Fitri*[1)], Febiola Putri Yunita[1)], Arizal Mujibtamala Nanda Imron[2)], Lalitya Nindita Sahenda[1)] and Angga Mardro Raharjo[3)]

[1)]Department of Information Technology, Politeknik Negeri Jember, East Java, Indonesia
[2)]Department of Electrical Engineering, Universitas Jember, East Java, Indonesia
[3)]Department of Medicine, Universitas Jember, East Java, Indonesia

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Abstract

Acute respiratory infections (ARI) encompass diseases with epidemic prevalence and mortality (measured number of deaths in a population) worldwide. Several types of diseases are classified as acute respiratory infections (ARI), i.e., pneumonia, diphtheria, tuberculosis, and COVID-19. The Ministry of Health of Indonesia suggests that one of the performance indicators for infectious disease control and management is disease detection. Disease detection constitutes the most significant factor for infectious diseases, and early detection based on the patient's symptoms is essential to classify and treat the diseases. The delayed treatment of these diseases has resulted in many cases and deaths, especially in ARI. Furthermore, to help support the Ministry of Health's program, an expert system was established to detect early acute respiratory infections (ARI) based on the patient's symptoms. Employing a combination of forward chaining and certainty factor as the expert system method could produce a percentage range of system accuracy of 95 to 97.5%.

Keywords: ARI, Certainty factor, Expert system, Forward chaining

1. Introduction

Acute respiratory infections (ARI) encompass diseases with epidemic prevalence and mortality (measured number of deaths in a population) worldwide [1]. Several types of diseases classified as acute respiratory infections (ARI) include pneumonia, diphtheria, tuberculosis, and COVID-19. Pneumonia, diphtheria, and tuberculosis are ARI diseases caused by bacteria [2]. The bacteria that cause pneumonia are *Streptococcus pneumoniae* and *Staphylococcus aureus* [3].*Corynebacterium diphtheria* is a bacterium causing diphtheria, while *Mycobacterium tuberculosis* is a bacteria that causes tuberculosis (TB) [4]. Corona virus disease, also known as COVID-19, is a disease triggered by a new virus that first appeared in Wuhan, China, and up to this point, the virus has been mutating into various variants. The Ministry of Health of Indonesia suggests that one of the performance indicators for infectious disease control and management is disease detection [5]. Disease detection constitutes the most significant factor for infectious diseases, and early detection based on the patient's symptoms is essential to classify and treat the diseases. The delayed treatment of these diseases has resulted in many cases and deaths, especially in ARI. Furthermore, to help support the Ministry of Health's program, an expert system was established for the early detection of acute respiratory infections (ARIs) based on the patient's symptoms.

An expert system (ES) is a method of studying expert thinking and reasoning to solve problems, make decisions, and draw conclusions based on a set of facts (symptoms) [6-8]. Research on expert systems is commonly used for the diagnosis or early detection of human diseases [9-15], yet this does not exclude potential in other areas, such as agricultural management [16]. The diagnostic process begins with the system tracing the patient's symptoms to determine the type of disease. These symptoms serve as knowledge that will subsequently be matched with the rules the system has created. Rule-based systems can be established either by forward chaining or backward chaining [6]. Forward chaining is a forward tracing technique by collecting information on an object, compiling rules, and drawing a conclusion [13]. Meanwhile, the backward chaining method is a reverse search starting with observations from the results/conclusions, seeking several hypotheses against the facts that support these hypotheses [17]. Based on the research results conducted by Abdi, it was examined that the forward chaining method had higher system speed and data accuracy than the backward chaining method [18].

Some research utilizing rules based on the forward chaining method include expert systems for detecting infectious diseases in children [6], web-based diagnosis of acute respiratory infections (ARI) [19], diagnosis of fungal skin diseases [20], the identification of damaged cars [21], and the determination of the characteristics of students with special needs [22]. However, several studies have combined the forward chaining method with other methods, such as the certainty factor method. The certainty factor (CF) method is a method on expert systems that describes an expert's confidence level by indicating the level of belief according to the expert's knowledge [10, 11, 23, 24]. Some studies have combined these two methods to rice crop management [16] or narcissistic personality disorder [25], tuberculosis (TB) [12], pulmonary disease (9), rheumatic disease [8], fever (dengue hemorrhagic fever, malaria, typhoid)

*Corresponding author.
Email address: zilvanhisnaef@polije.ac.id
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[13]. In previous studies, the adoption of the forward chaining and certainty factor methods for the results of the fever early detection case study (dengue hemorrhagic fever, malaria, and typhoid) had an accuracy of 95% [13]; therefore, this method was further adopted and applied to other studies, for example, investigating the early detection of acute respiratory infection (ARI).

In this study, we compared the symptoms of diphtheria, tuberculosis (TB), pneumonia, and COVID-19. We adopted the combination of forward chaining and certainty factors to build an expert system for the early detection of acute respiratory infections (ARI), especially in Jember Regency, Indonesia, involving expert pulmonary specialists serving as a lecturer and a doctor at a public hospital in Jember Regency.

2. Materials and methods

An expert system is a computer program that collects information i.e., facts and knowledge, to solve problems effectively and efficiently in fields that require many sources of knowledge and expensive expertise [26]. An expert system consists of several interconnected parts, namely the inference engine, knowledge base, database, user interface, and explanation facilities, as shown in Figure 1.

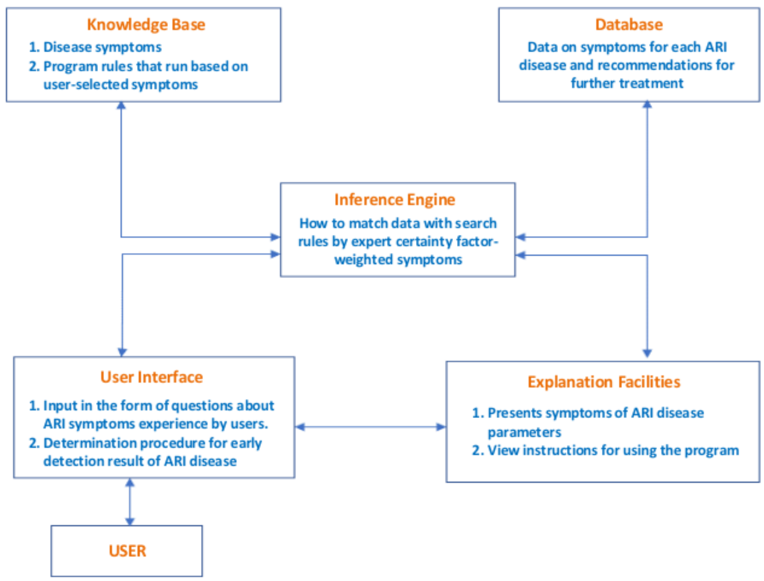

Figure 1 Block diagram of an expert system [26].

2.1 Knowledge base and database

The knowledge base covers a list of ARI symptoms (pneumonia, diphtheria, tuberculosis, Covid-19) and rules based on the symptoms experienced by users. Furthermore, the database comprises data on the symptoms and recommendations for future treatment. Data collection methods include literature reviews and interviews with experts, namely dr. Angga Mardro Raharjo, Sp.P, a lecturer at the Faculty of Medicine, Universitas Jember, as well as a pulmonologist working at Dr. Soebandi Hospital. Based on the results of literature reviews and interviews with experts, there were 4 codes for the types of Acute Respiratory Infection (ARI) (Table 1) and 41 symptoms for the 4 types of ARI (Table 2).

2.2 Inference engine

An inference engine implements the human thought process by extracting information from a database and providing answers, predictions, and suggestions like a human expert. This study uses two methods: forward chaining and certainty factor. Forward chaining is an advanced search technique by collecting known facts and combining them into rules to draw conclusions [13]. The determination of forward chaining rules in the system results from the author's discussion with our experts about the symptoms of each disease presented in Table 3. The table specifies the code A001 for symptoms of tuberculosis or TB (P001), A002 for symptoms of COVID-19 (P002), A003 for symptoms of diphtheria (P003), and A004 showed symptoms of pneumonia (P004).

Table 1 Codes and names of the diseases

Number	Code	Disease Name
1	P001	Tuberculosis (TB)
2	P002	COVID-19
3	P003	Diphtheria
4	P004	Pneumonia

Table 2 Code, disease symptoms, and the certainty factor score according to the experts.

No.	Code	Symptom of diseases	P001	P002	P003	P004
1	G001	Travel out of town or abroad within a week	0.8	1	1	1
2	G002	Fatigue or weakness (Malaise)	1	1	0	0.6
3	G003	Decreased appetite	1	0	0	0
4	G004	Sore (Myalgia)	0	1	0	0
5	G005	Nausea or vomiting	0	0.6	0.2	0.2
6	G006	Impaired taste (can't taste the food)	0	1	0	0
7	G007	Anosmia (can't smell)	0	1	0	0
8	G008	Weight loss	1	0	0	0
9	G009	Sweating at night for no reason	1	0	0	0
10	G010	Sneezing	0	0.6	0	0.2
11	G011	Throat pain	0	0.8	1	0
12	G012	Hoarseness	0	0	1	0
13	G013	Flu	0	0.6	0	0.2
14	G014	Headache	0	1	1	0.2
15	G0015A	Continuous Cough	1	0.4	0	0
16	G0015B	Frequent Cough	0.8	0	0	1
17	G0015C	Rare Cough	0	0	1	0
18	G0016A	Cough with Phlegm	1	1	0	1
19	G0016B	Bleeding Cough	1	0	0	1
20	G0016C	Hacking Cough	0	1	1	0
21	G0017A	Yellow or greenish phlegm	1	1	0	1
22	G0017B	Red phlegm	1	0	0	1
23	G0017C	Colorless phlegm	0	1	1	0
24	G0018A	Cough more than 21 days	1	0	0	0
25	G0018B	Cough less than 14 days	0	0.4	0	1
26	G0018C	Cough less than 7 days	0	0	1	0
27	G0019A	Fever with a temperature of 39 °C	0	0	0	1
28	G0019B	Fever with a temperature of 38 °C – 39 °C	1	1	0	0.8
29	G0019C	Fever with a temperature of 37 °C – 37.9 °C	0	0	1	0
30	G0020A	Fever more than 21 days	1	0	0	0
31	G0020B	Fever less than 14 days	0	1	0	1
32	G0020C	Fever less than 7 days	0	0	1	0
33	G0021	Chest pain	0.2	0	0	0
34	G0022	Breathless	0.6	1	0	1
35	G0023	Noisy breathing	0	0	0	1
36	G0024	Fast heart rate	0	0.4	0.8	1
37	G0025	White or gray spots on tonsils	0	0	1	0
38	G0026	Found a lump on the back of the neck	0	0	1	0
39	G0027	Have a history of HIV/AIDS disease	1	0	0	0
40	G0028	Have a history of congenital diseases (diabetes, coronary heart disease, high blood pressure, asthma, kidney, and cancer)	1	1	0	0
41	G0029	Have had direct contact with patients with acute respiratory infections (ARI)	1	1	1	1

Table 3 Code and rules on the exysysispa expert system

No.	Code	Rule
1	A001	IF [G001] AND [G002] AND [G003] AND [G008] AND [G009] AND [G0015A] AND [G0015B] AND [G0016A] AND [G0016B] AND [G0017A] AND [G0017B] AND [G0018A] AND [G0019B] AND [G0020A] AND [G0021] AND [G0022] AND [G0027] AND [G0028] AND [G0029] THEN P001
2	A002	IF [G001] AND [G002] AND [G004] AND [G005] AND [G006] AND [G007] AND [G0010] AND [G0011] AND [G0013] AND [G0014] AND [G0015A] AND [G0016A] AND [G0016C] AND [G0017A] AND [G0017C] AND [G0018B] AND [G0019B] AND [G0020B] AND [G0022] AND [G0024] AND [G0028] AND [G0029] THEN P002
3	A003	IF [G001] AND [G005] AND [G0011] AND [G0012] AND [G0014] AND [G0015C] AND [G0016C] AND [G0017C] AND [G0018C] AND [G0019C] AND [G0020C] AND [G0024] AND [G0025] AND [G0026] AND [G0029] THEN P003
4	A004	IF [G001] AND [G002] AND [G003] AND [G005] AND [G0010] AND [G0013] AND [G0014] AND [G0015B] AND [G0016A] AND [G0016B] AND [G0017A] AND [G0017B] AND [G0018B] AND [G0019A] AND [G0019B] AND [G0020B] AND [G0022] AND [G0023] AND [G0024] AND [G0029] THEN P004

Based on the rules presented in Table 3, a calculation is performed using the Certainty Factor (CF) method with the following equation [13]:

$$CF[a,b] = CF[rule] * CF[expert] \quad (1)$$

$$CF_{combination}[CF_1, CF_2] = CF_1 + CF_2 * (1 - CF_1) \quad (2)$$

$$Percentage\ of\ Rule = Highest\ of\ CF_{combination} * 100\% \quad (3)$$

2.3 User interface and explanation facilities

A User Interface manages the interaction between the user and the system through menus, questions, and responses displayed in the expert system's results. The User Interface (UI) functions to help the user understand the information conveyed by the expert system [16]. An expert system equipped with a User Interface (UI) is a form of artificial intelligence computer that asks questions to the user and then responds to the answers like an expert or doctor to provide an early diagnosis of a disease [26]. Furthermore, the Explanation Facilities is a part that shows parameter symptoms in each ARI disease and instructions for using this expert system.

2.4 System testing

Testing the system to obtain the level of accuracy of the system in the early detection of Acute Respiratory Infection (ARI) based on the symptoms experienced by the patient is matched with the expert's diagnosis result. The percentage of accuracy of the system is subsequently calculated by the following formula:

$$System\ accuracy = \frac{Amount\ of\ test\ data\ depending\ on\ the\ target}{amount\ of\ test\ data} x100\ \% \quad (4)$$

The other tools function to analyze or evaluate system performance through calculations on the confusion matrix. The confusion matrix is an N x N matrix, where N is the number of classes adjusted to the target to find true positives, true negatives, false positives, and false negatives [27]. Furthermore, it can be calculated to determine accuracy and precision, as in Figure 2.

		Actual Class	
		Positive	*Negative*
Predicted Class	*Positive*	*True Positive* (TP)	*False Positive* (FP)
	Negative	*False Negative* (FN)	*True Negative* (TN)

Figure 2 Confusion Matrix

Accuracy is the comparison of the positive and negative prediction results with the overall data. Precision is the comparison of the real positive predictive value (TP) with the overall positive prediction results (TP and FP).

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} x100\ \% \quad (5)$$

$$Precision = \frac{TP}{TP + FP} \quad (6)$$

3. Results

After the system is built, the system must be tested by users or patients by entering data on the symptoms they are experiencing on the "Exysysispa" web application. In the first step, the patient is asked to enter their personal data consisting of full name, age, telephone number, address, and gender. Furthermore, the display will change to a question related to the symptoms experienced by the user after the user selects the start detection button. There are 29 questions related to symptoms that may be experienced by the user (Figure 3). The user is also asked to choose four answer options, namely very sure, sure, a little sure, and not sure, with the score of the answers determined in Table 4. Afterward, the user should answer 29 questions related to the symptoms that may be experienced; for example, referring to Table 5, the system calculates the CF value for each existing rule by determining which rule has the highest share value (learning rules by grouping data, and CF values for user-selected symptoms).

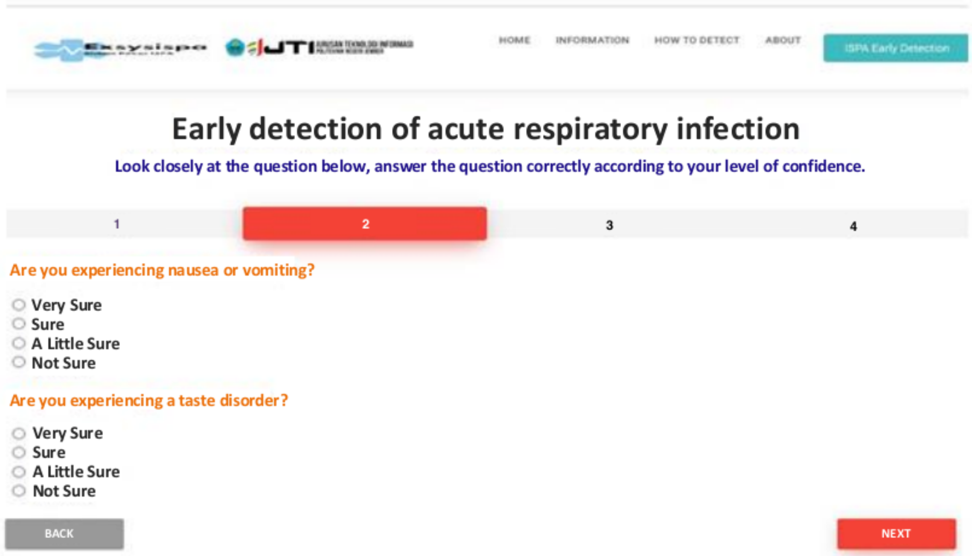

Figure 3 Display containing questions about symptoms the user may be experiencing.

Table 4 Choices according to the score of the answer selected by the user.

No.	Answer	The score of the answers
1	Very sure	1
2	Sure	0.8
3	A little sure	0.4
4	Not sure	0

Table 5 Code, symptoms, and the certainty factor score from the user

No.	Code	Symptom of diseases	User's CF
1	G001	Travel out of town or abroad within a week	0.4
2	G005	Nausea or vomiting	0.8
3	G010	Sneezing	0.4
4	G011	Throat pain	1
5	G012	Hoarseness	1
6	G014	Headache	0.6
7	G0015B	Frequent Cough	0.4
8	G0016C	Hacking Cough	0.6
9	G0017C	Colorless phlegm	0.6
10	G0018B	Cough less than 14 days	0.2
11	G0019C	Fever with a temperature of 37 °C – 37.9 °C	1
12	G0024	Fast heart rate	0.8
13	G0025	White or gray spots on tonsils	1

3.1 CF value calculation based on the rule.

Based on user-experienced symptom data (Table 5), the certainty factor of each rule was calculated to discover the rule with the highest percentage.

Rule 1: G001, G0015B
Rule 2: G001, G005, G0010, G0011, G0014, G0016C, G0017C, G0018B, G0024
Rule 3: G001, G005, G0011, G0012, G0014, G0016C, G0017C, G0019C, G0024, G0025
Rule 4: G001, G005, G0010, G0014, G0015B, G0018B, G0024

The calculation was based on Rule 1 (A001) (Table 3), which was then calculated using the equation formula of (1) – (3); the results are displayed in Table 6. Further, Rule 2, Rule 3, and Rule 4 were also calculated, and the percentage results are presented in Table 7.

Table 6 Calculation result CF rule 1

No.	CF Symptom	CF Combine	Percentage of Rule 1
1	0.32	0.32	
2	0	0.32	
3	0	0.32	
4	0	0.32	
5	0	0.32	
6	0	0.5376	
7	0.32	0.5376	
8	0	0.5376	
9	0	0.5376	
10	0	0.5376	54%
11	0	0.5376	
12	0	0.5376	
13	0	0.5376	
14	0	0.5376	
15	0	0.5376	
16	0	0.5376	
17	0	0.5376	
18	0	0.5376	
19	0	0.5376	

Table 7 The percentage of CF values is based on the type of ARI disease.

No.	Disease Name	Percentage of CF value
1	Tuberculosis (TB)	54%
2	COVID-19	99.81%
3	Diphtheria	100%
4	Pneumonia	96%

Based on the calculation results above, the highest percentage is indicated in diphtheria disease, with a percentage of 100%. Therefore, it can be concluded that based on the symptoms experienced, the user is suspected of being identified as having diphtheria as it demonstrates the highest percentage value among other diseases.

3.2 Analysis

To test the accuracy of the expert system, the researchers collaborated with dr. Angga Mardo Raharjo, Sp.P, a pulmonologist. The test aimed to identify the percentage of system accuracy based on user or patient symptoms for early detection of acute respiratory infections (ARI). Afterward, these symptoms were compared with the knowledge and results of the diagnosis from the expert. In this study, we conducted 20 case studies and divided them into 5 examples of symptoms in each acute respiratory infection (ARI), which the expert classified. Following this step, we input these symptoms into the expert's website system to discover the system's accuracy level. The test results of the case studies are shown in Table 8. This table portrays the system test results in collaboration with the expert. The system accuracy was calculated by adding the equation formula of (4) to get the results, resulting in 95%. Apart from that, we also examined the accuracy and precision of the system's test data based on the calculation results of the confusion matrix displayed in Table 9.

Table 8 Expert system test results

No.	Target	System Outputs	The highest percentage of CF value	The compliance of the test results with the expected target	
				Compliance	Incompliance
1	Tubeculosis (TB)	Tubeculosis (TB)	100%	√	
2	Tubeculosis (TB)	Tubeculosis (TB)	100%	√	
3	Tubeculosis (TB)	Tubeculosis (TB)	100%	√	
4	Tubeculosis (TB)	Tubeculosis (TB)	96%	√	
5	Tubeculosis (TB)	Tubeculosis (TB)	96%	√	
6	COVID-19	COVID-19	100%	√	
7	COVID-19	COVID-19	90%	√	
8	COVID-19	COVID-19	96%	√	
9	COVID-19	COVID-19	100%	√	
10	COVID-19	COVID-19	90%	√	
11	Diphtheria	Diphtheria	95%	√	
12	Diphtheria	Diphtheria	96%	√	
13	Diphtheria	Diphtheria	96%	√	
14	Diphtheria	Diphtheria	100%	√	
15	Diphtheria	Diphtheria	100%	√	
16	Pneumonia	Pneumonia	100%	√	
17	Pneumonia	Pneumonia	100%	√	
18	Pneumonia	Pneumonia	90%	√	
19	Pneumonia	Pneumonia	90%	√	
20	Pneumonia	COVID-19	100%		√

Table 9 Confusion Matrix

		Actual Class			
		Tuberculosis (TB)	**COVID-19**	**Diphtheria**	**Pneumonia**
Predicted Class	Tuberculosis (TB)	5	0	0	0
	COVID-19	0	5	0	0
	Diphtheria	0	0	5	0
	Pneumonia	0	1	0	4

Based on the above confusion matrix data, the calculation of accuracy and precision for each class adopted equations (5) and (6) by discovering the values of True Positive (TP), True Negative (TN), False Positive (FP), and False Negative (FN) at first. Subsequently, these values were employed to find the accuracy and precision values displayed in Table 10.

Table 10 The calculation results of the system accuracy in each class of ARI diseases

Class	TP	TN	FP	FN	Accuracy (%)	Precision
Tuberculosis (TB)	5	15	0	0	100	1.000
COVID-19	5	14	1	0	95	0.833
Diphtheria	5	15	0	0	100	1.000
Pneumonia	4	15	0	1	95	1.000
Average					97.5	0.958

The average result of system accuracy using the confusion matrix calculation is 97.5%, while the precision value of system performance is 0.958. These results indicated that the system's accuracy and precision in the early detection of symptoms of acute respiratory infections were relatively high, with a percentage range of system accuracy of 95 to 97.5%. It was because the patient's symptoms should result in pneumonia, but the system detected it as COVID-19 symptoms. It can be concluded that pneumonia symptoms are similar to COVID-19; thus, further examination in hospitals is deemed necessary.

4. Discussion

Several research references and comparisons for this proposed research are listed in Table 11. According to this table, several literature studies employed different types of ARI(s) from the proposed research. However, the method combination of forward chaining and certainty factor suggests better accuracy than one single method (forward chaining or certainty factor). In addition, the system accuracy level is also influenced by the number of disease symptoms that have similarities to other diseases. Forward chaining only discovers the best rule in determining conclusions. On the other hand, the certainty factor can describe the confidence level of an expert by providing their confidence scale based on their knowledge of each symptom; thus, it can result in a better level of system accuracy, mainly if the disease indicates similar symptoms to others.

Table 11 Comparison of reference research with proposed research

Author	Research methods	Types of ARI	Results and Evaluation
Ramadhani T et al. [19]	Forward Chaining	Bronchitis, Sinusitis, Bronchiolitis, Pneumonia, Pharyngitis, Epiglottitis, Pleuritis, Common Cold and ILI (Influenza Like Illness)	This study resulted in a system accuracy rate of 94%, where the output results of the system are in contrast with the results by experts; for example, the system detects pleuritis, while the expert's diagnosis is pneumonia.
Gusmaliza D et al. [28]	Forward Chaining	ARI(s) in Children	This study only explains that the system can detect ARI(s) in children.
Elvitaria L et al. [29]	Certainty Factor	Covid-19	The system accuracy is 99.96%.
Wirasbawa N et al. [12]	Forward Chaining and Certainty Factor	Tuberculosis (TB)	This research can detect tuberculosis symptoms. However, it only focused on web-based applications connected to the API; thus, in further development, researchers should add other types of diseases as a comparison.
Neptiani A et al. [9]	Forward Chaining and Certainty Factor	Pneumonia, Tuberculosis, Lung Cancer, Asthma, Bronchitis, and Chronic Obstructive Pulmonary Disease	The results of the calculation test based on the symptoms input by the patient indicated the highest CF percentage value of 99.747%, with a diagnosis of asthma.
Irfan M et al. [27]	Forward Chaining and Certainty Factor	Asthma	This research diagnosed the level of asthma, but the results suggested an accuracy level of 65% and, a precision level of 58.3%.
Proposed research	Forward Chaining and Certainty Factor	Tuberculosis (TB), Covid-19, diphtheria, and pneumonia	Based on the symptoms input by the user, the system accuracy ranged from 95% to 97.5%, while the precision rate amounted to 0.958.

5. Conclusions

The combination of the forward chaining and certainty factor methods has resulted in an expert's system capable of early detection of ARI with a percentage of system accuracy ranging from 95 to 97.5%; thus, several other symptoms are required to be added to make a difference, particularly in pneumonia and COVID-19. According to discussions with the expert, further tests are necessary to distinguish pneumonia and COVID-19, such as antibody testing and Polymerase Chain Reaction (PCR) in the patient's blood. Since some previous studies states that most pneumonia is an infection due to fungi and bacteria; therefore, if pneumonia symptoms indicate to be caused by a virus, such as SARS-CoV-2, it is usually referred to as COVID-19.

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