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Optimization of Expert System Based on Interpolation, Forward Chaining, and Certainty Factor for Diagnosing Abdominal Colic

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Abstract: Abdominal colic is a common condition that affects infants and it can be difficult to diagnose because it shares many symptoms with other conditions, such as gastric disease and appendicitis. Limitations of existing diagnostic methods include the unreliability of physical examinations and medical histories and the high cost and time-consuming nature of imaging tests. This research proposes an expert system based on interpolation, forward chaining, and certainty factors for diagnosing abdominal colic. This system has the potential to provide a more accurate and efficient way to diagnose abdominal colic, which could lead to better patient outcomes. This research proposes an expert system based on interpolation, forward chaining, and certainty factors for diagnosing abdominal colic. This system is implemented as a web application model. The forward chaining method is used to establish rules for the expert system. The rules are based on the symptoms and diseases that are included in the system's knowledge base. The interpolation method is used to normalize lab results and the certainty factor method is used to process medical history and physical examinations. This is necessary because medical history and physical examinations can be imprecise. The expert system was tested on a dataset of 100 cases and it was able to accurately diagnose 96 patients, achieving a 96% accuracy rate. This suggests that the expert system has the potential to provide a more accurate and efficient way to diagnose abdominal colic, which could lead to better patient outcomes.

Keywords: Abdominal Colic, Certainty Factor, Forward Chaining, Interpolation, Surgery

Introduction

Abdominal colic is a common condition that affects infants and can be difficult to diagnose because it shares many symptoms with other conditions, such as gastric disease and appendicitis. Misdiagnosing abdominal colic can have serious consequences, such as delayed treatment and increased risk of mortality for patients undergoing surgery. Abdominal colic is also often mistaken for a common stomach problem, leading to 259 million undiagnosed cases of appendicitis in men worldwide. The results of interviews with specialist surgeons at Qadr Hospital indicate that during surgery, other diseases are often encountered in addition to the diagnosed condition. This condition increases the risk of mortality for patients undergoing surgery, as surgeons performing the operation must work beyond the predetermined time, which can be physically exhausting and impact their concentration and performance during the surgical procedure. Therefore, a thorough diagnosis is necessary to provide additional considerations to the doctor when making decisions.

Abdominal pain is stomach pain that occurs due to enlargement, blockage, or inflammation of organs in the abdominal area. Chronic abdominal pain is a challenging complaint for both primary care providers and gastroenterologists alike due to a broad differential diagnosis and sometimes extensive and negative workup (Sabo *et al*., 2021). This pain can occur suddenly, as well as develop gradually and become chronic. This pain is often accompanied by nausea, vomiting, diarrhea, or fever (Doherty, 2015). Gastritis is inflammation of the stomach lining characterized by discomfort in the upper abdomen, in addition to nausea, vomiting, loss of appetite, and headaches (Umasugi *et al*., 2020). Gastritis can be the beginning of a serious and challenging-to-treat illness. According to the WHO, the percentage of gastritis cases in Indonesia is 40.8% (Al Baihaqi, 2021).

This research proposes a web-based expert system to assist doctors in diagnosing abdominal colic and identifying other diseases that a patient may concurrently experience. The expert system will use a combination of interpolation, forward chaining and the certainty factor to normalize patient laboratory data, establish rules for diagnosing abdominal colic, and process medical history and physical examinations. The certainty factor will also be used to weigh the expert's confidence level.

Interpolation is a method for estimating the value of a function at a point between two known data points. In the context of the proposed expert system, interpolation will be used to normalize patient laboratory data. This is necessary because laboratory results can vary depending on the patient's age and other factors. Forward chaining is a reasoning method that starts with known facts and then uses rules to infer new facts. In the context of the proposed expert system, forward chaining will be used to establish rules for diagnosing abdominal colic. These rules will be based on the symptoms and diseases that are included in the system's knowledge base. The certainty factor is a measure of the belief in a hypothesis. It is used to combine the evidence from multiple sources into a single measure of belief. In the context of the proposed expert system, the certainty factor will be used to process medical history and physical examinations. This is necessary because medical history and physical examinations can be imprecise.

A number of studies have been published on the challenges in diagnosing abdominal pain. For example, a study published in the journal Gastroenterology found that the median time to diagnosis of appendicitis was 24 h. The study also found that 20% of patients with appendicitis were misdiagnosed at least once.

Another study published in the journal the American journal of gastroenterology found that the accuracy of physical examination findings in patients with abdominal pain was only 60%. The study also found that imaging tests such as X-rays and ultrasound were only able to identify the underlying cause of abdominal pain in 20-30% of cases.

These studies highlight the significant challenges that clinicians face in diagnosing abdominal pain. The broad differential diagnosis, vague and nonspecific symptoms, nonspecific physical examination findings, and limited accuracy of imaging tests all contribute to these challenges.

Based on previous studies, an interpolation method is needed to normalize patient values in terms of laboratory data performed by Raditya *et al*., (2020). It shows that using the certainty factor results in a higher level of accuracy, reaching 96%, compared to Dempster-Shafer, which achieves 94%. The certainty factor will be responsible for weighting the values of doubt or uncertainty, both in the process of patient history taking and physical examination, as well as weighting the expert's confidence level.

Other research was conducted by Abdillah and Innuddin (2019) which shows that the use of forward chaining and certainty factor results in an accuracy of 80%. Forward chaining functions to form rules based on the data of symptom and disease values provided by experts. There are two contributions to this research. First, the combination of forward chaining method, certainty factor, and interpolation for diagnosing abdominal colic disease with 29 symptoms and 14 diseases.

Second, the use of user confidence value weights tailored to the user's consultation form, one of which utilizes the Numeric Rating Scale (NRS) function. (Walker *et al*., 2018). The benefit of this expert system is that it can produce patient diagnoses with a high level of accuracy. Research related to expert systems using the forward chaining method was conducted by Hafizal *et al*. (2023). The expert system addresses potassium deficiency in cocoa plants using the forward chaining method (Pahlevi and Atmojo, 2020). Utilization of an expert system for diagnosing cocoa plant diseases based on Android using the forward chaining method.

This research proposes a novel web-based expert system that uses a combination of interpolation, forward chaining, and the certainty factor to diagnose abdominal colic and identify other diseases that a patient may concurrently experience. The expert system has the potential to improve the accuracy and efficiency of abdominal colic diagnosis, leading to better patient outcomes and reduced burden on doctors.

Materials

This study utilizes high-performance computing servers as its hardware foundation, offering detailed specifications to illuminate the computational environment. The expert system is constructed on a sophisticated software framework integrating interpolation algorithms, forward chaining reasoning mechanisms, and certainty factor calculations, with meticulous documentation of software versions for experiment replicability. The diverse dataset for expert system training and testing originates from clinical cases related to abdominal colic, accompanied by transparent explanations of data acquisition, preprocessing, and potential biases. Employing both retrospective data from historical medical records and prospective data from standardized surveys and expert interviews, the paper thoroughly elucidates the data collection processes.

Furthermore, specialized medical instruments, approved by healthcare authorities, are employed alongside detailed explanations of interpolation and forward chaining tools for data collection. The statistical analysis, intricately incorporating these tools, maintains transparency in the expert system's decision-making process. Essential preprocessing steps, including noise reduction and outlier detection, enhance data quality, crucial for precise diagnostic outcomes. The comprehensive detailing of the experimental setup, encompassing patient demographics and clinical scenarios, not only contributes to the scientific rigor of the paper but also fosters reproducibility and potential advancements in the field of expert systems for abdominal colic diagnosis.

Methods

The research conducted involves several stages. These stages aim to give direction to the research. Figure 1 shows the flow of the applied methods. The stages in the sequence include data collection, data preprocessing, forward chaining method, interpolation method, certainty factor method, and testing.

Figure 1 represents the research stages starting from data collection preprocessing, followed by exploration using the forward chaining method, followed by determining the user's weight range for laboratory data using the Interpolation method and assigning weights with the certainty factor.

The data collection stage is divided into 2 phases: First, obtaining data from surgical patients at Qadr Hospital in Tangerang. This data represents patients after undergoing surgery. Second, conducting interviews with experts or specialist surgeons regarding abdominal colic-related diseases and their symptoms.

The preprocessing stage employed is the data transformation stage, which involves converting the original data format into a new data format. The format change involves splitting columns containing symptom lists into one symptom per column. This format change is applied to ensure that the data can be correctly interpreted by the system. This will minimize the risk of analysis errors due to an inappropriate format.

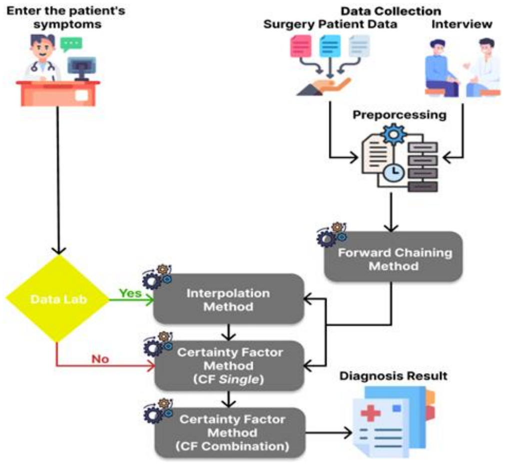

Fig. 1: The research stages

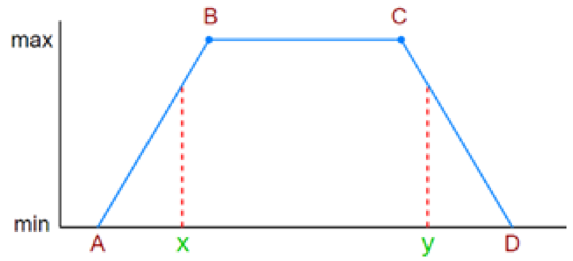

Fig. 2: Interpolation graph

Forward chaining is a search technique that begins with information in the form of facts to test the truth of hypotheses and then attempts to draw conclusions (Abdillah and Innuddin, 2019; Irfan *et al*., 2022). This stage is useful for forming or describing rules that are derived from the collected data.

In this stage, lab data is processed using the interpolation method first. This is done to determine the weight of the values that the user inputs before they are processed into the certainty factor method. There are three types of interpolation: Ascending, descending, and horizontal.

Based on Fig. 2 in the Ascending Interpolation, as the x-value approaches point B, the x-value gets closer to the maximum. Conversely, when the x-value approaches point A, the x-value will get closer to the minimum. Ascending interpolation in the Formula (1).

Descending interpolation, as the y-value approaches point D, the y-value gets closer to the minimum. Conversely, when the y-value approaches point C, the y-value gets closer to the maximum. Descending interpolation in the Formula (2):

$$Value(y) = \frac{(y-D)}{(C-D)} \times (min - max) + max \quad (2)$$

The certainty factor method was developed by the MYCIN developers, who found that medical experts express their confidence levels in terms that are difficult to define or explain mathematically. MYCIN introduced the certainty factor, also known as the certainty factor, to quantify the confidence of medical experts into numerical values (Negnevitsky, 2005). After determining the user's weight values for numerical symptoms processed in advance with the interpolation method, the user consultation data processing continues using the certainty factor method. The application of this method will be processed in two stages, with the first stage being the calculation of a single *CF* using the Formula (3). The second stage involves calculating the Combination *CF* using the Formula (4) (Pakpahan *et al*., 2019; Pane *et al*., 2020):

$$CF(H,e) = CF(E,e) \times CF(H,E) \quad (3)$$

E = Evidence
e = Evidence e

H = Hypothesis (diseases)
CF (H, e) = Certainty factor based on H Evidence e
CF (E, e) = The value of e against E that is input by the user
CF (H, E) = The value of E to H is determined by a medical expert

$$CFC = CF_1 + CF_{n+1} \times (1 - CF_1) \quad (4)$$

CF_1 = First CF, then CF results of the previous combination
CF_n+ = CF next until n

The testing phase will utilize two types of tests: Application testing, namely black-box testing. Wilsen *et al*. (2020); Purnomo *et al.* (2020) and accuracy testing of the system's calculations, which is the confusion matrix (Soetanto, 2018; Suryadewiansyah and Tju, 2022). Application testing will ensure that the system operates normally without any errors and in accuracy testing, the doctor's diagnosis results will be compared to the system's diagnosis results to measure how many diagnoses match in order to assess the accuracy level of this system.

Results and Discussion

The results of this research make clearer the information regarding the data used. The presented case study provides a comprehensive picture of how the method is applied. Application testing results and accuracy testing of the system being built.

Disease and Symptom Data

Disease data is derived from expert interviews and an analysis of surgical patient data. This research involves 14 types of abdominal colic diseases, as clearly reflected in Table 1. The table contains a list of disease codes and names that are the focus of this study.

In this research, 29 types of symptoms are used. Table 2 contains a list of codes and names of the symptoms that are the focus of this study. These data represent symptoms commonly found in abdominal colic patients and were obtained through a literature review process and interviews with specialist surgeons.

Expert Confidence and Interpolation Value

Results from interviews and evaluations by specialist surgeons led to the formation of 222 expert belief value rules. These values are included in Table 3. The data is derived from the knowledge and experience of experts in their field. These values serve as expert CF (Certainty Factor) values in the certainty factor formula.

Interpolation value data resulted in 84 rules in Table 4. The interpolation values are used to normalize laboratory data. The determination of these interpolation points is based on the knowledge held by experts in their field. This is supported by a literature study related to the diseases under investigation.

Table 1: List of disease code and name

Code	Disease name	Code	Disease name
D01	Peptic ulcer	D08	Intestinal perforation
D02	Cholelithiasis	D09	Urinary tract infection
D03	Liver abscess	D10	Nephrolithiasis
D04	Apendix	D11	Ureterolithiasis
D05	Colitis	D12	Ovarian cyst rupture
D06	Intestinal TBC	D13	Ectopic pregnancy
D07	Colon cancer	D14	Acute pancreatitis

Table 2: List of symptom code and names

Code	Symptom	Code	Symptom
G01	Female gender	G16	Rebound pain
G02	Age	G17	Upper abdominal pain
G03	Abdominal pain	G18	Mid-abdominal pain
G04	Nausea/ vomiting	G19	Right lower abdominal pain
G05	Epigastric pain	G20	Left lower abdominal pain
G06	Decline in condition	G21	Lower abdominal pain
G07	History of gastritis	G22	Back abdominal pain
G08	Flatulence	G23	Generalized abdominal pain
G09	Shifting pain	G24	Intermittent
G10	Diarrhea	G25	Continuous
G11	Weight loss	G26	Bloody stool
G12	Fever	G27	Leukocytes
G13	Hyperactive bowel sounds	G28	Decreased hemoglobin
G14	Palpable mass	G29	Leukocyturia
G15	Tenderness		

Table 3: Value determined by experts

Code	D01	D02	D03	…	D12	D13	D14
G01	0.00	0.00	0.00	…	0.30	0.30	0.00
G02	0.10	0.10	0.10	…	0.10	0.10	0.10
G03	0.30	0.30	0.30	…	0.30	0.30	0.30
G04	0.30	0.30	0.30	…	0.25	0.25	0.30
G05	0.35	0.35	0.35	…	0.20	0.20	0.35
G06	0.00	0.00	0.00	…	0.00	0.00	0.30
…	…	…	…	…	…	…	…

Table 4: Interpolation point values on data

Code	Symptom ID	Disease ID	Value A	B	C	B	Measure	Category
I01	G02	D01	7.0	20.0	50	60	Year	Trapezoid
I02	G11	D02	0.0	1.3	0	0	kg	Ascending
I03	G12	D03	37.5	40.0	42	0	°C	Descending
I04	G27	D04	10000.0	25000.0	50000	0	uL	Descending
I05	G28	D05	1.0	13.0	17	25	g/dL	Trapezoid
I06	G29	D06	1.0	5.0	500	0	lpb	Descending
…	…	…	…	…	…	…	…	…

Table 5: Interpolation of intestinal perforation

Parameter	n	Score (n)
G02	56.0	0.40
G11	0.9	0.69
G12	38.0	1.00
G27	26400.0	0.72

Rule Based

There are 14 rules or regulations formed based on symptom data and disease data. These rules are established using the forward chaining method supported by expert assessment for each symptom and disease. For example, rule data is Rule 1 (R1) states that if a patient experiences symptom with codes G02, G03, G04, G05, G07, G08, G10, G11, G13, G15, G16, G17 and G25, then the patient is diagnosed with the disease with code D01. These rules are formed through the forward chaining method based on research data obtained.

Case Study

A case study of a male patient, 56 years old, experiencing severe abdominal pain rated at 9/10. In one day, he vomited six times, had a 4/10 pain level in the upper abdomen, and felt extremely weak and warm, with a rating of 9/10. Over the course of a week, he had gastric problems three times, felt certain about experiencing discomfort when passing gas, believed the pain frequently moved, had one bowel movement per day, lost 0.9 kg in weight over one week, had a body temperature of 38°C during examination and had highly active bowel sounds rated at 9/10. He felt very painful during a palpation examination, experienced pain during release, felt pain throughout the abdomen but concentrated in the central area, experienced continuous pain, and had a leukocyte count of 26,400 μL, a hemoglobin count of 13 g/dL, and four lab leukocyturia.

In the case study, the patient's lab data needs to be normalized first using the interpolation method before it can be processed into certainty factors. This normalization is intended to measure the user's belief value or *CF* user. The determination of the minimum value as 0 and the maximum value as 1 aims to align it with the calculation of certainty factors. Table 5 is an example calculation of interpolation based on the rules specified in Table 4.

The symptom data input by the user in the consultation form will be processed using the certainty factor method. If this data is laboratory data, it will first be normalized using the interpolation method. Table 6 is an example calculation of the Single Certainty Factor (CF). The user's weight value (*CF* user) is multiplied by the expert's weight value (*CF* expert).

Table 6: CF single intestinal perforation

CF (H, e)	CF (E, e) × CF (H, E)	Result
CF 1 (G2)	0.4×0.10	0.040
CF 2 (G3)	0.9×0.30	0.270
CF 3 (G4)	0.6×0.30	0.180
CF 4 (G5)	0.4×0.30	0.120
CF 5 (G6)	0.9×0.30	0.270
CF 6 (G7)	0.4×0.20	0.080
CF 7 (G8)	0.8×0.20	0.160
CF 8 (G9)	0.8×0.30	0.240
CF 9 (G10)	0×0.30	0.000
CF10 (G11)	0.69×0.10	0.069
CF11 (G12)	1×0.30	0.300
CF12 (G13)	0.9×0.10	0.090
CF13 (G15)	1×0.30	0.300
CF14 (G16)	0.8×0.35	0.280
CF15 (G18)	1×0.45	0.450
CF16 (G23)	0.8×0.30	0.240
CF17 (G25)	0.8×0.30	0.240
CF18 (G27)	0.72×0.20	0.144

Table 7: CF combination intestinal perforation

CFC	$\mathrm{CF}_1 + \mathrm{CF}_{n+1} \times (1 - \mathrm{CF}_1)$	Result
CFC 1	0.040+0.27×(1-0.04)	0.299
CFC 2	0.299+0.18×(1-0.299)	0.425
CFC 3	0.425+0.12×(1-0.425)	0.494
CFC 4	0.494+0.27×(1-0.494)	0.631
CFC 5	0.631+0.08×(1-0.631)	0.660
CFC 6	0.660+0.16×(1-0.66)	0.715
CFC 7	0.715+0.24×(1-0.715)	0.783
CFC 8	0.783+0×(1-0.783)	0.783
CFC 9	0.783+0.069×(1-0.783)	0.798
CFC10	0.798+0.3×(1-0.798)	0.859
CFC11	0.859+0.09×(1-0.859)	0.872
CFC12	0.872+0.3×(1-0.872)	0.910
CFC13	0.910+0.28×(1-0.91)	0.936
CFC14	0.936+0.45×(1-0.936)	0.964
CFC15	0.964+0.24×(1-0.964)	0.973
CFC16	0.973+0.24×(1-0.973)	0.979
CFC17	0.979+0.144×(1-0.979)	0.982

The process of calculating the single *CF* is complete and we now move on to the stage of combined *CF*. This stage is carried out by combining the results of each single *CF*. In the first iteration, CF_1 will be combined with CF_2. In subsequent iterations from the second to the nth, the result of the previous Combined *CF* will be combined with CF_{n+1}. Table 7 provides an example calculation of the combined *CF*.

Test Results

Testing the application model using the black-box method was conducted and evaluated by experts. There are seven components and 31 testing points. The testing results indicate that the application model runs smoothly, meeting all testing points without any errors. Table 8 is an attachment containing the results of the application model testing.

The testing was conducted to evaluate the accuracy of the system using 100 patient data. These data are from patients who underwent surgery at Qadr Hospital. Table 8 has two columns of conclusions, namely the actual and predicted column. And then the data from both columns are compared. This is done to determine whether the conclusions match or not, with the aim of measuring the level of accuracy. The accuracy testing results based on 100 patient surgery data have been validated by a specialist surgeon (expert). The confusion matrix method is used to measure the accuracy of the system diagnostic results. The results of the test were that out of 100 data tested, there were four patient data whose results did not match the results of the system diagnosis. In the surgical patient data, there is no patient data that has a negative value or is not experiencing pain, so TN and FN have a value of 0. Accuracy calculations using the confusion matrix produce an accuracy level of 96.

Table 8: Sample of experiment results

Patient	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	Gn+1	G26	G27	G28	G29	Actual	Predicted
Patient-26	P	54	8	3	5	0	0	N	RR	1	0.0	37.7	0	N	…	N	7480	16	14	D10	D10
Patient-27	P	44	5	4	4	0	0	RR	N	1	0.0	36.0	1	Y	…	N	8760	16	4	D12	D12
Patient-28	L	27	8	4	0	0	0	N	Y	1	0.0	36.0	0	N	…	N	8890	14	9	D11	D11
Patient-29	L	56	9	6	4	9	3	Y	Y	1	0.9	38.0	9	N	…	N	26400	13	4	D08	D08
Patient-30	L	29	6	4	2	7	0	N	RR	2	0.3	36.0	0	N	…	N	10110	16	14	D09	D09
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…

Overall, the results of the research indicate that the proposed expert system is a promising tool for diagnosing abdominal colic. The system is accurate and reliable and it has the potential to improve the quality of care for patients with abdominal pain.

Conclusion

The research results for the diagnosis of abdominal colic using the interpolation and certainty factor methods have resulted in a web application model. This model has the potential to assist doctors in the diagnosis of abdominal colic by providing them with additional insights and considerations.

The combination of the certainty factor and interpolation methods has proven to be effective in diagnosing abdominal colic, with an accuracy rate of 96% from 100 patient data. This accuracy rate suggests that the model can be used to reliably diagnose abdominal colic in patients.

While the research results are promising, there are a few areas where further research is needed. One area is the consultation form. The consultation form could be made more efficient and effective by streamlining the questions and reducing the amount of time it takes to complete.

Another area for further research is building an expert system consisting of more than 29 consultation forms. This would allow the system to diagnose a wider range of diseases, but it is important to consider the potential for patient overwhelm. If the consultation form is too long, patients may be less likely to complete it.

Finally, further research is needed to align the disease solutions with the data provided by the patients. This would ensure that the system is providing the most accurate and relevant recommendations to doctors.

Overall, the research results for the development of a web application model for diagnosing abdominal colic are encouraging. The model has achieved a high accuracy rate and has the potential to be a valuable tool for doctors. However, further research is needed to improve the efficiency and effectiveness of the consultation form, to build an expert system that can diagnose a wider range of diseases, and to align the disease solutions with the data provided by the patients.

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Author’s Contributions

Hari Soetanto: Initiate research projects, develop research conceptual frameworks, carry out data analysis and interpretation, give final approval of the version to be submitted and any revised version.

Painem: Drafted the article, reviewed the layout and grammar of article, provide input on the results of improvements from a scientific perspective.

Muhammad Kamil Suryadewiansyah: Assist with the data acquisition process, set up experimental environments, develop model implementations, and help analyze research finded.

Ethics

The authors confirm that this manuscript has not been published elsewhere and that no ethical issues are involved.

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