Expert Triage System in Cardiology Emergency Department

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Summary

Hospital challenges and employing artificial intelligence to tackle those challenges has been the topic of copious research. A key issue in any hospital is the triage unit which is ever more significant in heart specialized hospitals. Employing artificial intelligence methods especially the fuzzy method is a great help to medical diagnosis and prioritizing the patients in the cardiac ward.

In the present research, the Mamdani's fuzzy model was used to prioritize the triage rules in the hospital cardiac ward. As a developmental study, the present research aimed to propose and evaluate the patient prioritization system applied in the triage of a heart specialized hospital.

The system evaluation results obtained from the data provided by 200 patient visitors of Rajaei Cardiovascular, Medical & Research Center revealed that the proposed system, which enjoyed a sensitivity of 93% , accuracy of 96% and specificity of 97%, managed to have a proper prediction of the level of triage in the heart emergency room. The system also has this privilege that it has observed almost all the key factors involved in predicting the level of triage.

Fuzzy logic has come to the help of medical specialists. The present research used Mamdani fuzzy algorithm to classify patients in terms of their initial vital signs, nurses' and doctors' diagnosis. The proposed algorithm is capable of predicting of triage level in the heart emergency room with a sensitivity of 93%, accuracy of 96% and specificity of 97%.

Key words:

Fuzzy systems, fuzzy inference engine, triage level prediction, vital signs.

1. Introduction

A key issue in medical emergency especially for cardiac patients is setting priorities in the hospital triage. Difficulty of classifying emergency patients to such groups as outpatients, inpatients, terminally ill and ill along with an incorrect triage of patients can have negative consequences including death. There is, therefore, a need for a proper triage system which would guarantee the accuracy of the triage [1-3].

Due to the fact that in the majority of emergence wards, the five-level ESI (Emergency Severity Index) is used to prioritize patients, and in some cases it is hard for the nursing staff to set priorities, it is essential to propose an intelligent method based on the fuzzy logic to prioritize patients[1, 3].

The fuzzy inference system (FIS) is a systematic process to convert a database to a nonlinear mapping. That is why knowledge-based fuzzy systems are used for engineering, medical and decision-making purposes [4-6].

The fuzzy inference system is to map inputs to outputs using membership functions and fuzzy rules. It is in fact a system which executes human experiences via membership functions and fuzzy rules. It is a general method of combining knowledge, intelligent technology, control and decision-making. Among the best fuzzy inference models are Mamdani, Takagi, Sugeno and Tsukamoto. Among these, those of Mamdani and Sugeno are the most widely used [7-10].

The fuzzy theory is an important tool to face the ambiguity-induced uncertainty. Though fuzzy systems describe indefinite and uncertain phenomena, the fuzzy theory is a precise theory. The fuzzy set was for the first time introduced by Professor Lotfizadeh in a dissertation entitled as: "Information and control fuzzy sets" in 1965 and was practically applied in 1970s. This decade was marked by the advent of fuzzy controllers in actual systems [5, 11-13].

The fuzzy logic is a big achievement in the fuzzy set in which the variables are linguistic rather than numerical. The fuzzy logic can be contrasted with the Boolean or Aristotelian logic which sees all values as binary, 0 or 1, black or white, yes or no. On the other hand, in the fuzzy logic, values vary between 0 and 1.

A fuzzy system is comprised of the following components:

- A fuzzification in the input which converts the

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numerical value of variables to a fuzzy set.
- The fuzzy rule base which includes a set of if-then rules.
- A fuzzy inference motor which converts the input data to a set of output in a certain procedure.
- A fuzzification which converts the fuzzy output to an absolute numerical value [4, 5]

Mamdani inference system was proposed by Mamdani and Asilian in 1975. With their inherent visual and interpretive nature in the face of rules, these systems can be widely applied in decision support systems. They also possess such a power of expression that enables them to be executed both in the Multiple-Input-Multiple-Output (MIMO) and the Multiple-Input-Single-Output (MISO) modes [9, 10, 14].
The present research also employed Mamdani fuzzy inference system.
Figure 1 indicates the overall diagram of Mamdani fuzzy inference system.

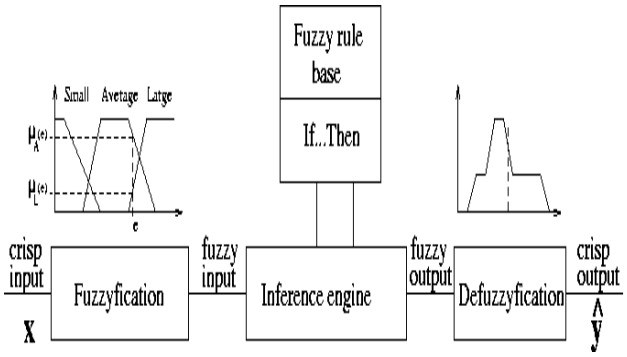

Fig. 1 Mamdani inference system

On the other hand, the term triage is derived from the French trier which implies categorization or selection. It refers to the prioritization of patients who should not be waiting long. Triage systems have been established based on the nurses' assessment of vital signs, objective and subjective information, medical history allergies and medicines prescribed to set the sensitivity of the triage. In most HERs, triage is done through the ESI flowchart [15]
The complexity of medical systems changes system analysis fundamentally [16, 17]. Thus, to describe such systems, their fuzziness should be addressed in traits. One such system to which the fuzzy logic is successfully applied is the triage prioritization system[18, 19].
The fuzzy logic enables the classification and prioritization of patients through a triage based on the fuzzified input and extracted rules [10, 11, 14]. In this research, initially the vital signs, as the input, were obtained from Shahid Rajaie hospital system and were mapped, according to the fuzzy logic, to values between 0 and 1, then they were converted to if-then rules by a panel of experts and according to the triage rules. The final output was in the form of 1-5 (level 1 to 5) classes of triage (emergent, urgent and non-urgent).
Shohas Dutta et al. conducted their research entitled as: "Using fuzzy logic for decision support in vital signs monitoring"[4]. They employed the fuzzy logic to predict patient's health state based on their vital signs. The accuracy of the method applied was reported to be 85%. Similarly, Cicilia RM Leite et al. in some other research entitled as: "A fuzzy model for processing and monitoring vital signs in ICU patients", employed the fuzzy logic to help physicians to set triage levels in the ICU based on such vital signs as T, RR, HR, BP and SPO2. The accuracy of this approach was reported to be 85%[7].
A review of the related literature showed there is no comprehensive system to predict cardiac patients' triage level taking into account all the risk factors [6, 11, 20]. The proposed model followed the rules in the fuzzy system database. The risk factors upon admission were taken into account and the cardiac patients' triage level was predicted accordingly.

2. Theoretical Consideration

As an evaluative and development investigation, this research paper aimed to propose and evaluate a system for cardiac patients' prioritization in the HER. To this aim, Mamdani fuzzy algorithm was adopted[5, 12].
For system evaluation, the data within patients' medical records in 2017 were used. Accordingly, 200 cases were selected as the sample.
In this research, the input was comprised of the vital signs filled in a form as can be viewed in Table 1. Fuzzy rules were extracted by a panel of experts including the nursing and physician staff of Shahid Rajaie HER. Eventually the output was comprised of the prioritization rules to be applied to cardiac patients referring to the triage room. A mixed method was followed to use ESI together with the comments of a panel of experts and it all resulted in 5 classes/levels.

Table 1: Inputs of fuzzy system

Membership function	Distance	Abbreviation	Input
MF1='less_than_80':'trimf',[60 70 80] MF2='between_80-140':'trimf',[80 110 140] MF3='mre_than_140':'trimf',[140 170 200]	[60,200]	Bp/s	Systolic blood pressure
MF1='less_than_60':'trimf',[40 50 60] MF2='between_60-80':'trimf',[60 70 80] MF3='mre_than_80':'trimf',[80 100 120]	[40,120]	BP/d	diastolic blood pressure
MF1='more_than_180':'trimf',[180 185 190] MF2='mre_than_160':'trimf',[	[95 185]	HR	Heart Rate

160 172.5 185] MF3='mre_than_140':'trimf',[140 162.5 185] MF4='more_than_100':'trimf', [100 142.5 185]			
MF1='more_than_50':'trimf',[50 55 60] MF2='more_than_40':'trimf',[40 50 60] MF3='more_than_30':'trimf',[30 45 60] MF4='more_than_20':'trimf',[20 40 60]	[15 55]	RR	Respirator y Rate
MF1='more_than_38':'trimf',[38 40 42] MF2='more_than_39':'trimf',[39 41 43]	[35 45]	T	Temperat ure
MF1='less_than_92'trimf',[80 90 100]	[80 100]	SPO 2	oxygen saturation
MF1='less_than_3month':'gua ssmf',[0.1 0.35] MF2='between_3month_&_3 year':' guassmf ',[0.3 3.5] MF3='between_3y-8y':' guassmf ',[3 8.5] MF4='more_than_8y':' guassmf ',[8 100]	[0.1,1 00]	Age	Age
MF1='is':'trimf',[1 1 1] MF2='is_not':'trimf',[0 0 0]	[0 1]	Pulse	Pulse
MF1='is':'trimf',[1 1 1] MF2='is_not':'trimf',[0 0 0]	[0 1]	Bruis e	Bruise
MF1='is':'trimf',[1 1 1] MF2='is_not':'trimf',[0 0 0]	[0 1]	Cons cious ness	Conscious ness
MF1='is':'trimf',[1 1 1] MF2='is_not':'trimf',[0 0 0]	[0 1]	pain	pain

As the first step, the system input was fuzzified via a fuzzy approach. In this stage, once each input was obtained, its degree of membership of was estimated through membership functions. The output of this stage was a fuzzy value which showed the degree to which the input was a member of the fuzzy set. This output always ranged from 0 to 1.

As the second step, when the input was fuzzified, the accuracy degree of each component was determined. When the assumption had several parts, fuzzy operators were used.

As the third step, decisions were made based on an evaluation of all rules. The result of the consensus was a fuzzy set for each output variable and the fuzzy output which changed to a non-fuzzy value was reported numerically.

Finally, to estimate system efficiency, a table was drawn to compare the system results with those within patients' medical records. Then formulas 1-3 were used to estimate accuracy and sensitivity values. In this research, accuracy implies the extent to which patients referring to the target hospital HER are provided with a triage visit. Moreover, sensitivity is a criterion describing the errors in a fuzzy classification to prioritize patients admitted to the HER of Shahid Rajaie medical, research-based and university hospital.

1) Accuracy: Tp+FN/TP+TN+FN+FP[17]
2) Sensitivity: TN/TN+FP[17]

The rules extracted from a survey of a panel of experts (nurses) were 8 in number. They are indicated in Table 2. To validate, the triage classification system the MATLAB software was used due to its open access and quick display. The data extracted from patients' medical records in Shahid Rajaie hospital entered the proposed system and the results of the system were compared to those recorded in the actual triage by the nursing staff. Then, the accuracy and sensitivity were reported.

Table 2: Rules of fuzzy system

Rule no.	Rules
Rule 1	If the person is a child, HR is high, RR is high, SPO2 is low, and then the patient will be classified as level 3.
Rule 2	If the person is a new born, HR is high, RR is high, SPO2 is low and the temperature is abnormal, then the patient will be classified as level 3.
Rule 3	If the person is a baby, HR is high, RR is high, SPO2 is low and the temperature is abnormal, then the patient will be classified as level 3.
Rule 4	If the person is an adult, HR is high, RR is high, SPO2 is low, and then the patient will be classified as level 3.
Rule 5	If the person is an adult, heart rate is normal and the patient is not bruised, if s/he is conscious and feels little pain, then the patient will be classified as level 4.
Rule 6	If the person is an adult, there is no heart rate and the patient is bruised, unconscious and feels pain, if the systolic pressure is high and diastolic pressure is high, and then one will be classified as level 1.
Rule 7	If the person is an adult and the patient is not conscious and feels pain, then s/he will be classified as level 2.
Rule 8	If the person is an adult and heart rate is normal, the patient is not bruised and s/he is conscious and feels little pain, if the diastolic pressure is normal and systolic pressure is normal, then the patient will be classified as level 5.

The data belonged to the 2017 record. A sample was selected from Morgan Table[21]. Figures 2-4 indicate the key membership functions. The system acquired the input data and used the existing rules and produced the final output data.

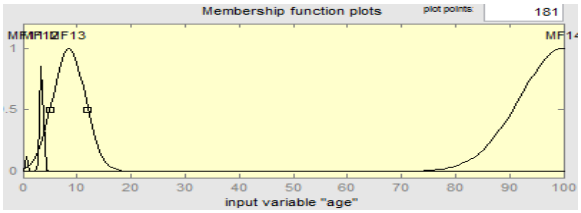

Fig. 2 Membership functions of age

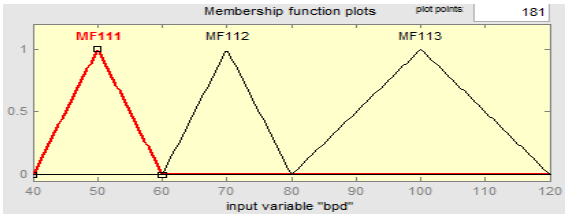

Fig. 3 Membership functions of Blood pressure

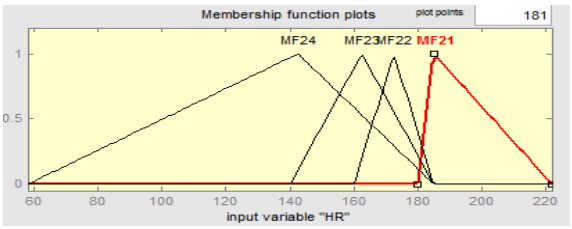

Fig. 4 Membership functions of heart rate

3. Experimental Consideration

Once system evaluation was done based on a fuzzy approach, the accuracy and sensitivity were reported as in Table 3. The system evaluation was done through a report of accuracy and sensitivity. A fuzzy approach was used in the design phase. As more vital signs were taken into account in the present research than the related literature, we managed to raise system sensitivity to a significant extent.

Table 3: Comparison of Fuzzy model and the other reported methods

Method	Results
Fuzzy based triage in this article	Sensitivity: 93% Accuracy: 96% Specificity: 97%
Manual triage	Sensitivity: 84% Accuracy: 75% Specificity: 70%

In the fuzzy system, to view and compare the relation of inputs and outputs better, the Surface diagram can be used which can now be observed in Figure 5. It shows the correlation of patient's heart rate and age.

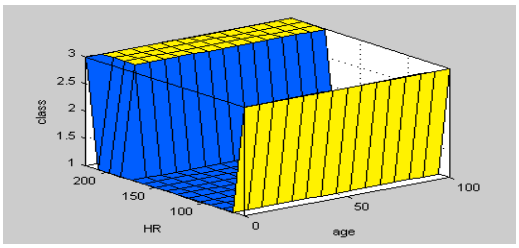

Fig. 5 The Surface diagram of age and heart rate

In the light of the higher accuracy and sensitivity of this system, it can be easily trusted by the medical and nursing staff in their attempts to classify patients' triage level. This method is compared with the other available methods in table 3 On the other hand; employing artificial intelligence especially the fuzzy logic in uncertain conditions can be highly efficient.

The present research proposed a new algorithm based on intelligent fuzzy systems to predict patients' triage level in the HER of Shahid Rajaie hospital. The proposed algorithm enjoys high accuracy and sensitivity. The proposed approach extracted patients' data from their medical records organized them and entered them into a fuzzy system. The given fuzzy system algorithm possessed 11 inputs and 5 outputs. The former is comprised of the vital signs which significantly affect cardiac patients' triage levels. The latter has got 5 levels ranging from 1 to 5.

The analysis results of a sample of 200 medical records revealed that the proposed algorithm managed to diagnose the triage levels of cardiac patients with a sensitivity of 93%, accuracy of 96% and specificity of 97%.

Not only can the proposed system improve the sensitivity of prior methods used in predicting cardiac patients' triage level[4, 7, 22], but it also enjoyed the use of a real dataset from actual cardiac patients in Tehran province to do the test. The present findings lead us to certain suggestions which contribute to a better application of the proposed approach:

- Healthcare organizations all over the country are advised to set up similar systems to that of the present research to help medical centers decide on cardiac patients' triage level and accelerate the diagnosis and reference of patients to a hospital which has a cardiac team of specialists.
- Medical universities are suggested to oblige their computer programmers as well as their medical staff to enter patients' comprehensive medical record in this software. This helps to provide a more comprehensive account of a patient's medical history and cuts down on the need to refer to the medical records. However, in the majority if hospitals including Shahid Rajaie cardiac hospital just the test results enter the given software.

So as to improve the administration of the present system and to develop the proposed approach, many things can be done including:

- The use of learning algorithms to choose the best properties. This was done in the present research through consulting with a heart specialist. However, learning algorithms can be employed to do a better selection.
- To use learning algorithms to better mix the risk factors and access a more effective combined property.

4. Conclusion

The present research aimed to diagnose cardiac patients' triage level following a fuzzy approach considering patients' vital signs. The proposed model was designed, implemented and validated using a real database. Using the fuzzy approach in medicine can have many useful implications. It can assist the field specialists. The present

work attempted to take into account as many vital sign as possible so as to raise system accuracy and sensitivity.

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