

Research Article

Decision Support System to Risk Stratification in the Acute Coronary Syndrome Using Fuzzy Logic

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Acute coronary syndrome (ACS) is a set of symptoms and signs which define a range of conditions related with the unexpected reduced blood flow to the heart. In ACS, the heart muscles cannot function properly due to the decrease of blood flow. Myocardial infarction (MI) is a condition which comes under the umbrella of acute coronary syndrome. The aim of risk stratification (RS) in ACS is to recognize patients at high risk of ischemic events. Yet, no investigative study is available to identify the patients at high risk. Therefore, to facilitate this process, it would be ideal to have a reliable and trustworthy method by the help of which the doctors can make early and easy decisions for the patient and for detecting the related disease. This research used the features of GRACE Score to RS in the ACS and presented decision support system (DSS). The concept of probabilistic approach has been used as a tool to model the identified features for decision-making (DM). This technique can be further used for DM purposes to RS in the ACS in healthcare. Furthermore, the result of the proposed method has proved closer and more reliable DM of patient and then eventually can be used for advice of medicine and rest accordingly by the doctors.

1. Introduction

The emergency department is mostly facing the patient of chest pain. One of the main reasons for chest pain is the ACS which occurs in both short-term and long-term adverse prognosis. ACS is a set of symptoms and signs which describe conditions range connected with reduced flow of blood to heart. In ACS, heart muscles are unable to function properly due to decrease in blood flow. The aim of RS in ACS is to identify the patients at high risk of ischemic events.

According to the report of WHO [1], the cardiovascular disease is one of the top causes of death. In the admissions of hospital, the patients of acute chest pain are a big burden. This range is presented as the number present of 40% of acute medical admissions and 5% of all emergency [2]. On time and efficient treatment is a necessary part to ensure the cost-effective and precise management of the patient. Meanwhile, the poor identification and treatments are linked with increased mortality, morbidity, and cost [3]. The

identification of ACS relies on account of ischemic symptoms, such as the ischemic ECG changes, chest pain, and elevated cardiac biomarkers. There are diverse causes of ACS and the identification of MI is categorized based on the causes [4].

ACS is a multifactorial disease which includes the genetic factor caused by coronary artery obstruction by atheroma. It is influenced by other factors of risk such as diabetes, hypertension, obesity, smoking, and dyslipidemia. Among these, the hypertension and dyslipidemia are considered as the most common factors in the ACS patients, with a suggestion that preventing these factors can put in a decrease in the process of atherosclerosis. Diagnosis of patients with high risk soon after ACS has been a challenging issue for the clinicians for a few decades. Several studies exist which show that more rigorous management of the patient results in considerably good outcomes in the adverse cardiac events. The diagnosis of severity risk of ACS patient is significant, as the patient can get benefit with early and proper treatment.

Lin et al. [5] presented a study containing a dataset of 22 million enrollees in Taiwan from 1999 to 2010. The study has acknowledged 27948 patients with CS and sex, age, and comorbidity matched control. Multivariate regression analysis after amendment for probable cardiovascular confounders and odd ratios was calculated with 95% confidence interval to measure the relationship between CS and ACS.

The aim of the ACS risk score is to diagnose the patient with high risk who can be managed with optimum treatment in short time. The patients of ST elevation MI and non-ST elevation MI have been subjected to the RS studies and several risk scores have been proposed. Some of the scores were tested in clinical trial populations, while others were derived from large registries.

Currently, no exploratory study is available to recognize the patients with high risk. To assist this progression, it would be ultimate to have a reliable and trustworthy method through which the practitioners can make early and easy decision for the patient. The proposed study's contribution is to use the features of GRACE Score to RS in the ACS for DM. A probabilistic approach of fuzzy tool has been used to model the feature for DM. The technique can be further used for DM purpose to RS in the ACS in healthcare. Fuzzy set is an effectual tool to convey uncertain and imperfect cognitive information with the membership, nonmembership, and hesitance degrees [6]. The fuzzy logic has a wide range of applications in various areas of research [7]. Technology acceptance model was presented through fuzzy multicriteria DM approach [8]. The study has analysed 136 research articles regarding the software development organization for cloud based technology implementation.

This paper is organised as follows: Section 2 describes works related to RS in the patients of ACS. Section 3 describes the methodology used for the planned study. Section 4 depicts the results and discussions, while the paper concludes with Section 5.

2. Related Work

Early DM of patient has immense prospective for refining the value of care, decreasing the care cost, and dropping error and waste. Several studies were related to RS of patient for ACS. Singh and Guttag [9] presented an algorithm to hold class imbalance in medical datasets and assessed the nonsymmetric based classification tree algorithm performance. The performance of the said algorithm is evaluated and compared with those of SVM based classifiers applied to 4219 non-ST elevation ACS patients. Three strategies were used for management class imbalance. These strategies were synthetic minority oversampling, cost-sensitive SVM learning, and random majority undersampling. Khalil et al. [10] assessed the validity and accuracy of Canadian-ACS risk score as a prognostic score for the patient in hospital with RS with ACS as compared to TIMI and GRACE risk scores in patients of Egypt. The authors of [11] assessed the clinical utility of H-FABP for suspected ACS. The H-FABP demonstrated the added value to cardiac troponin in the initial stage after onset of symptoms. The H-FABP also detected the

patients at enlarged risk for upcoming actions of cardiac diseases. J. Přeček et al. [12] demonstrated a summary of patients with ACS of prognostic stratification according to baseline levels of renal function biomarkers. The authors of [13] provided a model with interpretable representation of long-term ECG recording and discovered the associations among all short heart rate patterns across the population of patients. The experiment was performed on 4557 patients with non-ST elevation ACS and confirmed that heart rate topic models considerably get better RS.

Macdonald et al. [14] compared the two clinical scoring methods of RS of suspected ACS in the emergency department. Cullen et al. [15] performed a diagnostic study in the emergency department for the patient with symptoms of ACS with two-hour sensitive Troponin Assay Results. The results were elaborated using standard measures of test accuracy. The authors of [16] reviewed up-to-date methods in the emergency care for the identification and RS of NSTEMI-ACS. Further, the authors highlighted the limitations of the existing approaches and suggested the improvements in them. An approach was presented which quantified the level to which subtle ECG morphology changes from beat to beat. The time and shape characteristics were considered as morphological variability to measure the changes in these variables in the cardiac events in sequential pairs of heart beats. The proposed method tested 400 patients of ACS [17]. The research explored the challenges that manipulate the dietary choices from patient attending a secondary prevention clinic following MI [18].

Dellas et al. [19] studied the predictive performance of Heart-type Fatty Acid Binding Protein and integrated it into the ESC algorithm. A subanalysis study was presented for the disease of diabetes and peripheral arterial disease in the patient of RS admitted after ACS [20]. Hill et al. [21] presented a roadmap for computational cardiology. The approach consisted of three stages: (i) development of baseline model, (ii) disease simulation, and (iii) translation. The authors of [22] presented that there were some barriers in the RS appropriate implementation with ACS, so they proposed developing a simple and early score for RS of the ACS patient. The study was conducted to diagnose the risk factors for the ACS for the age below 40 years in the Slemani Cardiac Hospital, Sulaimaniyah, Iraq [23]. Pezawas et al. [24] presented a study on the risk of arrhythmic death in ischemic heart disease. The study was conducted for prospective, controlled, observer-blind RS for 10 years. Lin et al. [5] presented a study for the quantification of the relationship between cervical spondylosis and ACS. Details of some of the existing approaches are shown in Table 1. These approaches along with the publication year are given.

3. Methodology

ACS is a set of symptoms and signs which describe variation of conditions associated with the sudden, reduced blood flow to the heart. In ACS, the muscles of the heart are unable to function appropriately due to the reduction of blood flow. MI is a situation under the umbrella of ACS. The proposed research work uses the features of GRACE Score to RS in the

TABLE 1: Some of the existing approaches for RS.

S. no.	Reference	Method used	Paper	Year of paper
1	[25]	Coronary disease-ACS: RS	Report	2000
2	[17]	RS following ACS through electrocardiography for measuring variability in morphology	Conference	2008
3	[26]	Rapid RS in suspected ACS using serial multiple cardiac biomarkers: a pilot study	Journal	2008
4	[20]	Additive value of diabetes and peripheral arterial disease in the RS of patients admitted after an ACS: a subanalysis of the PAMISCA study	Journal	2009
5	[14]	Comparison of two clinical scoring systems for emergency department RS of suspected ACS	Journal	2011
6	[9]	A comparison of nonsymmetric entropy-based classification trees and support vector machine for cardiovascular RS	Conference	2011
7	[13]	Cardiovascular RS with heart rate topics	Conference	2012
8	[15]	Performance of RS for ACS with two-hour sensitive Troponin Assay Results	Journal	2014
9	[16]	RS in non-ST elevation ACS: risk scores, biomarkers, and clinical judgment	Journal	2015
10	[21]	Computational cardiology and RS for sudden cardiac death: one of the grand challenges for cardiology in the 21st century	Journal	2016
11	[27]	RS in ACS: graded by a new score?	Journal	2017
12	[28]	RS after ACS: scores, scores, and yet another score	Journal	2017
13	[24]	Risk of arrhythmic death in ischemic heart disease: a prospective, controlled, observer-blind RS over 10 years	Journal	2017
14	[5]	Risk of ACS in patients with cervical spondylosis	Journal	2018
15	[23]	Risk factors for ACS in patients below the age of 40 years	Journal	2018
16	[22]	ProACS risk score: an early and simple score for RS of patients with ACS	Journal	2017
18	[29]	A new RS tool for women with ACS	Journal	2018
19	[19]	RS of acute pulmonary embolism based on clinical parameters, H-FABP, and multidetector CT	Journal	2018

ACS. The concept of probabilistic approach (fuzzy tool) has been used to model the identified feature for DM. The following subsections briefly describe the details of the proposed method.

3.1. RS in the ACS. The aim of RS in ACS is to identify the patients at high risk of ischemic events. Early DM in healthcare system has massive potential for refining the quality of care and reducing the cost of care, waste, and error. The risk score of Global Registry of Acute Coronary Events (GRACE) is a tool of validated RS which has incremental predictive value for RS compared with the evaluation of clinical testing [16]. Some countries have partial implementation of GRACE Score in their emergency medicine. The age factor formulates an exponential input to the GRACE Score. The addition of new cardiac biomarkers into this identification pathway can allocate to early treatment stratification. The advantages of the strong GRACE Score [30, 31] are based on large registry, but the disadvantage lies in including variables at the time of existing admission (laboratory results), so it is not applicable for instant stratification. The related studies to RS are discussed in Section 2 of the paper.

3.2. Fuzzy Logic. The fuzzy logic (FL) is a mathematical tool used to resolve circumstances of vagueness and uncertainty. It was developed by Zadeh in 1965 [32, 33]. FL converts the specific analysis, deals with vague information, and offers a best decision in the presence of the vague and incomplete data. Some of the applications of FL are in control system, car transmission system, washing machines, vacuum

cleaner, and software system [7, 34–37]. Details concerning fuzzy idea can be found in the study in [32]. Messaoud et al. [38] used fuzzy logic for the application of cognitively stimulated use of speech information and to enhance microphone system. Liu and Zhang [39] integrated the picture fuzzy set and the linguistic term; the study has defined the picture fuzzy linguistic set (PFLS) and operations of picture fuzzy linguistic numbers for developing the Archimedean picture fuzzy linguistic weighted arithmetic averaging operator and presented various properties and special cases of this operator. They also proposed a method which deals with problem of multiattribute group DM on the basis of the developed A-PFLWAA operator. The reason behind the fuzzy logic used in the proposed is that it works in the situation of uncertainty and vagueness, while the other methods like AHP and ANP work in complex situations.

3.3. DSS for RS in ACS. Fuzzy logic is used as a DSS for the RS of the ACS. Liu et al. [40] extended the ensemble-based scoring system by using a fast extreme learning machine algorithm for neural networks. The patients of emergency department of Singapore General Hospital were examined and the features of 12-lead ECG parameters, heart rate variability, and vital signs were extracted. An ensemble-based scoring system-extreme learning machine (ESS-ELM) algorithm was proposed for the prediction of cardiac events. The features of GRACE Score are considered to model the proposed DSS. Figure 1 shows the European Society of Cardiology (ESC) rapid rule-out of ACS with hs-cTn algorithm [41]. Rapid rule-out of ACS with high-sensitivity troponin. Grace = Global Registry of Acute Coronary Events; ULN = upper limit of normal, 99th percentile of

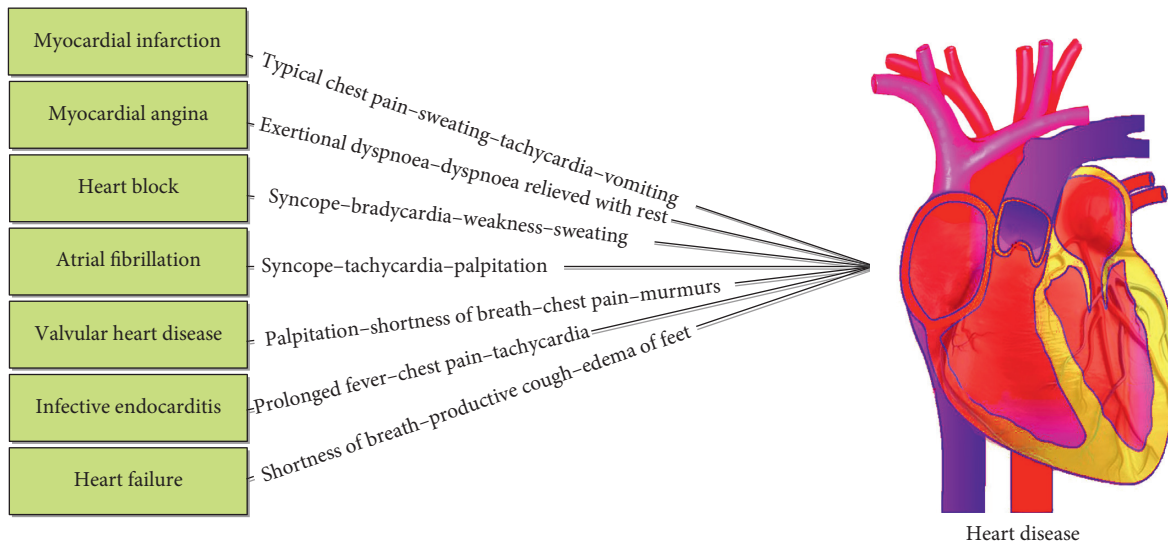


FIGURE 1: Graphical representation of heart diseases and their symptoms.

healthy controls; hsTn = high-sensitivity troponin. Figure 1 shows the graphical representation of heart diseases and their symptoms.

The GRACE 1.0 Score is broadly certified [41]. This score diagnoses the patient in hospital as a 6-month risk of death by using the following factors: heart rate, age, Killip class, systolic BP, creatinine, elevated cTn, ST-segment deviation, and cardiac arrest. The new GRACE 2.0 Score revised GRACE algorithms for diagnosis of death at 1 and 3 years and is termed at medical device (available at <http://www.gracescore.org/WebSite/WebVersion.aspx>). Figure 2 shows the GRACE score, which consists of the factors age, heart rate, systolic BP, Killip class, and creatinine [16].

Figure 3 shows the generic process of fuzzification and defuzzification modeling for the proposed study of RS for ACS. The figure consists of fuzzification, database, rule base, defuzzification, and output. Once the rules are designed based on the membership function, they can be stored in database provided by the fuzzy inference system. After that, the inputs can be passed from the designed model and the output will be displayed.

Membership functions are designed individually for each input based on the score provided in the GRACE Score table. The MFs are the degree of representations of each input. The starting and ending boundaries of a particular input can be shown. All the inputs are categorized into four membership functions. The reason behind this is that some of the inputs have fewer features, while some of them are having more detailed features. So, to make uniformity in the model, all inputs were equally categorized into four membership functions. These categories show the level and severity of a specific input. Figure 4 shows the memberships functions designed for the input age.

The rest of the membership functions for the other inputs can be drawn the same as Figure 4. The same can be plotted in the same way for the remaining membership functions.

Different rules were developed according to the defined membership functions. For understanding of the reader, some rules are given as follows:

- (i) *If Age (years) is 40, heart rate (bpm) is 70, systolic BP (mmHg) is <200, and Killip class is Class I) and creatinine (mg/dL) is 0.0–0.39, then risk stratification is very low (0.1)*
- (ii) *If Age (years) is 49–59, heart rate (bpm) is 89–109, systolic BP (mmHg) is 199–140, Killip class is Class I, and creatinine (mg/dL) is 0.4–1.19, then risk stratification is low (0.3)*
- (iii) *If Age (years) is 69–89, heart rate (bpm) is 110–199, systolic BP (mmHg) is 139–80, Killip class is Class I, and creatinine (mg/dL) is 1.2–3.99; then risk stratification is medium (0.5)*
- (iv) *If Age (years) is 69–89, heart rate (bpm) is 110–199, systolic BP (mmHg) is 139–80, (Killip class is Class II), and creatinine (mg/dL) is 1.2–3.99, then risk stratification is high (0.8)*
- (v) *If Age (years) is ≤ 90 , heart rate (bpm) is <200, systolic BP (mmHg) is >80, Killip class is Class IV, and creatinine (mg/dL) is > 4, then risk stratification is very high) (1) . . . and so on*

The proposed system is based on five inputs (age, Killip class, heart rate, systolic BP, and creatinine); rules and their output are shown in Figure 5. This system was designed in Matlab to deal with the situation of uncertainty and vagueness arising for the RS in the ACS. In this system, initially the membership functions are defined followed by the rules development from the MF, and the rules are combined to form the model. Inputs can be passed through the model and resulted output will be used to facilitate patient accordingly.

Figure 6 depicts the nomenclature of the proposed inputs, membership functions, rules, and output. The

Age (years)		Heart rate (bpm)		Systolic BP (mmHg)		Killip class		Creatinine (mg/dL)	
40>	0	70>	0	80>	63	Class I	0	0.0-0.39	2
49-40	18	89-70	7	99-80	58	Class II	21	0.4-0.79	5
59-50	36	109-90	13	119-100	47	Class III	43	0.8-1.19	8
69-60	55	149-110	23	139-120	37	Class IV	64	1.2-1.59	11
79-70	73	199-150	36	159-140	26			1.6-1.99	14
80-89	91	200<	46	199-160	11			0.2-3.99	23
90≤	100			200<	0			>4	31

FIGURE 2: GRACE Score.

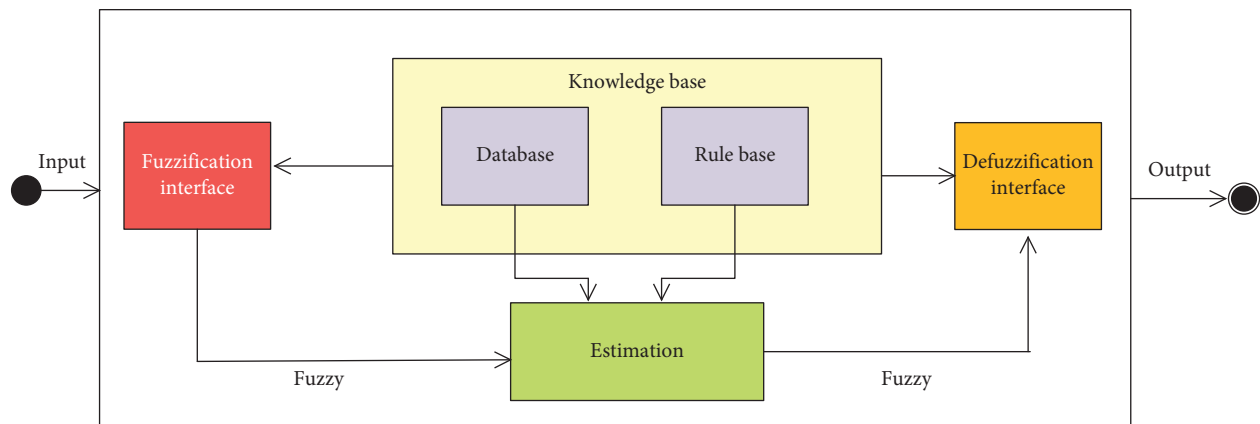


FIGURE 3: Generic process of fuzzy logic system.

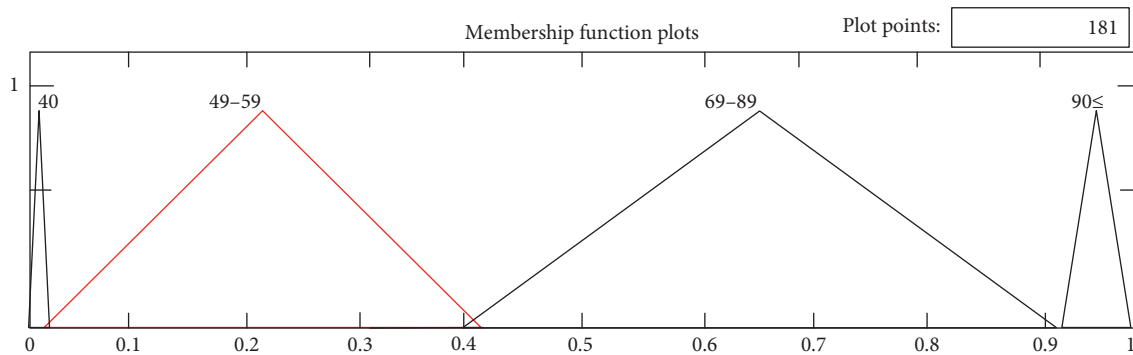


FIGURE 4: Membership functions designed for input age.

proposed system is generated in the fuzzy toolbox by using Matlab. In the figure, the initial black circles show the inputs that are the age, heart rate, systolic BP, Killip class, and creatinine, the second blank circles show the membership functions defined for the rules modeling, and the light-blue circles show the rules generated. Finally the output is shown in the figure and highlighted in black circle.

Figure 7 shows the graphical representation of the rules view obtained from membership function to design the rules and fuzzy inference system.

4. Results and Discussions

Once the model is designed from the membership functions for the variables of GRACE Score consisting of age, heart rate, systolic BP, Killip class, and creatinine. The fuzzy inference system of membership functions and rules are obtained. Different inputs of the same format are passed through the designed model to check the RS of the ACS. The range of the input and output values is between 0 and 1, where 0 shows the lowest range, while 1 shows the highest

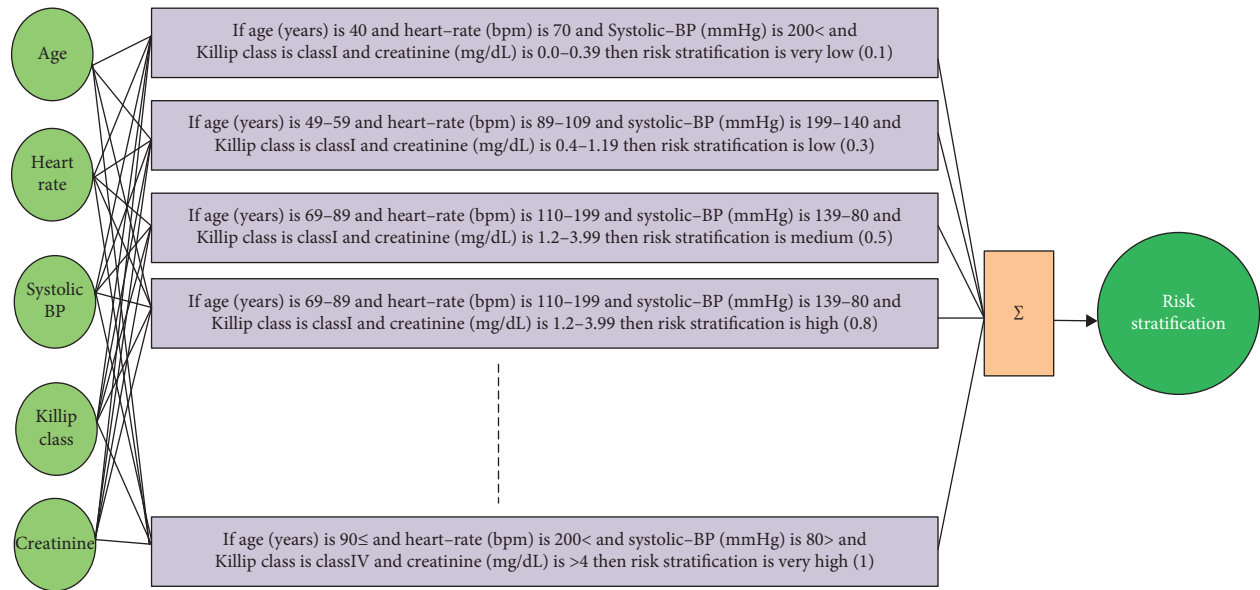


FIGURE 5: Proposed rules based system.

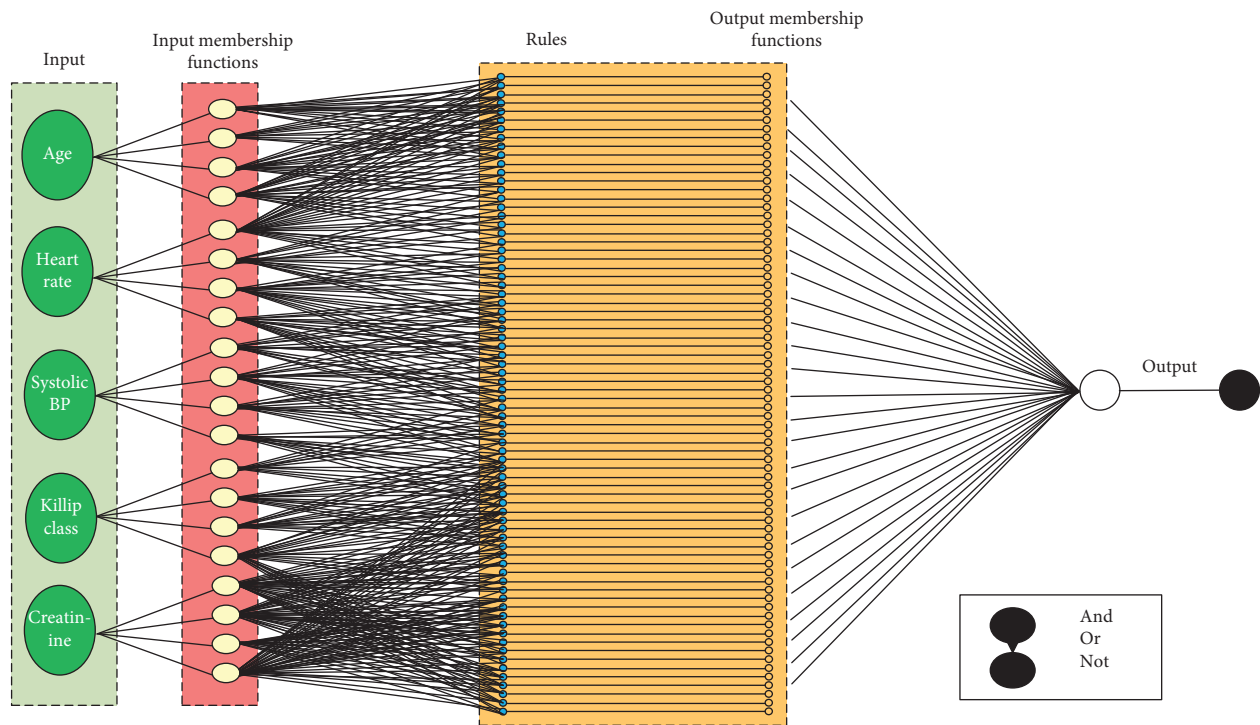


FIGURE 6: Taxonomy of the proposed inputs, membership functions, rules, and output.

range. The proposed system for risk stratification of ACS was checked and validated through a hypothetical input values. Later on, these values are confirmed from cardiologists to show the correctness of the method. The main part of this research is the design of model for RS of the ACS which was modelled in Matlab for the purpose of easiness and supporting healthcare. The values can be any digit for the features of the inputs depending on the patient's health status. Therefore, the proposed system was tested on

hypothetical values to show the validity of the research. Other approaches are available as mentioned in Section 2 and Table 2, which measure the RS in ACS from different perspectives.

None of the approaches mentioned in this paper calculate the RS in ACS based on the defined criteria in complex and uncertain situation. The proposed approach can easily and effectively measure the RS in ACS. Table 3 shows the inputs that passed through the model and their output. In

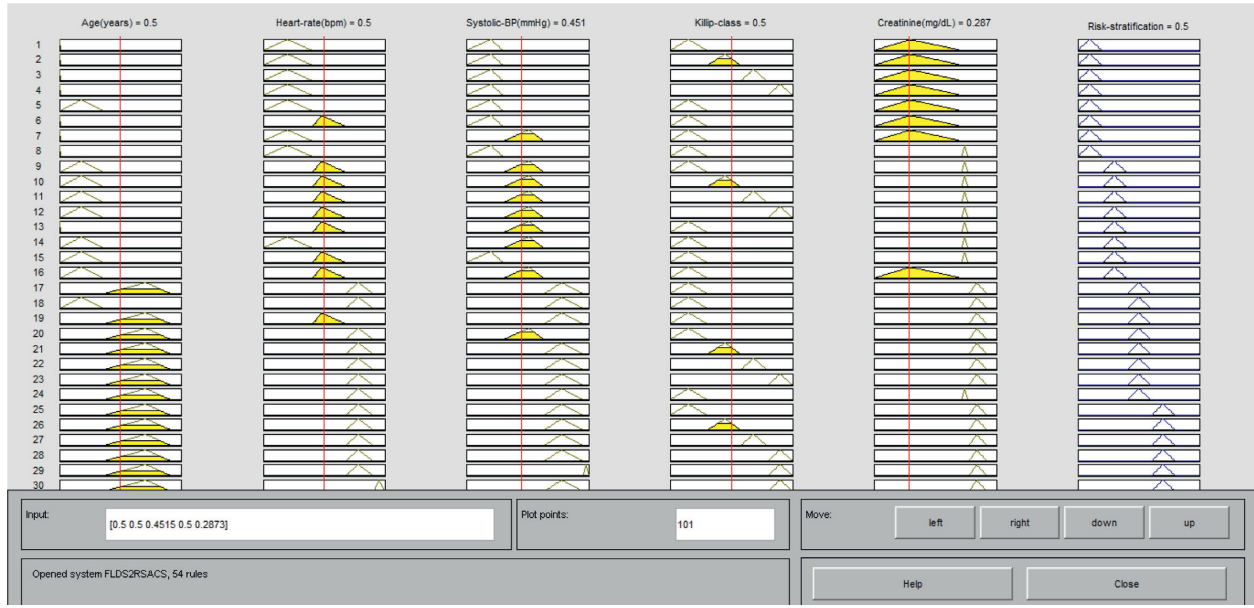


FIGURE 7: Graphical representation of rule view of the proposed system.

TABLE 2: Approaches for RS in ACS.

Reference	Method	Year
[42]	Biomarker algorithm encompassing the clinical chemistry score	2020
[43]	High-sensitivity cardiac troponin T in patients with suspected ACS	2020
[44]	Comorbidity assessment for mortality RS	2019
[45]	RS in ACS	2018
[46]	Role of cardiovascular reactions to mental stress challenge	
[43]	RS through high-sensitivity cardiac troponin T in patients with suspected ACS	2020
Our	Fuzzy logic based decision for RS in ACS	2021

TABLE 3: Inputs and their output of the proposed system.

Inputs	Age	Heart rate	Systolic BP	Killip class	Creatinine	Risk stratification
1	0.1	0.2	0.1	0.1	0.2	0.100
2	0.3	0.2	0.1	0.1	0.3	0.100
3	0.2	0.3	0.1	0.2	0.1	0.100
4	0.7	0.2	0.1	0.8	0.5	0.500
5	0.8	0.1	0.4	0.8	0.9	0.500
6	0.9	0.8	0.9	0.9	0.9	0.628
7	0.8	0.8	0.9	0.9	0.9	0.626
8	0.7	0.8	0.9	0.7	0.9	0.626
9	0.9	0.8	0.9	0.7	0.9	0.628
10	0.5	0.8	0.9	0.7	0.9	0.626
11	0.4	0.8	0.7	0.7	0.9	0.628
12	0.5	0.7	0.7	0.7	0.9	0.626

the table, the values are considered for 12 patients with different range of inputs for the same variables of GRACE Score. The proposed system can be checked on any sample size of patients. Recently, 12 sample sizes have been considered. It can be decreased and/or increased depending on the capacity of wards or hospital.

Later on, these values are plotted diagrammatically to make it easy for the practitioners in DM process. So from the above table, the level of RS can easily be identified.

5. Conclusion

ACS consists of signs and symptoms to define a range of situations linked with the sudden, reduced blood flow to the heart. The heart muscles are unable to function properly due to the reduction of blood flow in the ACS. The RS in ACS aims to recognize the patients at high risk of ischemic events. On time and initial DM in healthcare has enormous prospective for enlightening the quality of care, reducing the

cost of care, and reducing waste and error. To assist the said process, the proposed research work uses the features of GRACE Score to RS in the ACS. It will be a reliable and trustworthy method by the help of which the doctor can make early and easy DM for the patient and for detecting related disease. FL approach has been used as a tool to model the feature of GRACE score for DM in the ACS. The result of the proposed method has proved more close and authentic DM of the patient and can be used for advice of medicine and rest accordingly by the doctors. In the future, the proposed research can be explored to a more reliable and efficient system with large sample size to show the effectiveness and usefulness of the system for enhancement in healthcare. This will be further an enhanced step toward improvement in healthcare.

Data Availability

No data are available.

Conflicts of Interest

The authors declare no conflicts of interest.

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