Mamdani fuzzy rule-based models for psychological research

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Abstract

The biasness of the participants in psychological research cannot be ignored during answering various psychological questionnaires or inventory. Hence, the prediction of psychological parameters can be deemed an ambiguous endeavor and fuzzy modeling provides a mean to account for this ambiguity and uncertainty. In the present study, two fuzzy rule-based models that use single input and generate single output are developed to convert the raw scores of neuroticism and extraversion to standard scores. Maudsley personality inventory (MPI) and Sinha's comprehensive anxiety test (SCAT) were used to collect raw data of neuroticism, extraversion and anxiety from participants. Using the standard scores for neuroticism and extroversion, third fuzzy rule-based model is also developed to predict the anxiety level of the participants. Each model is a collection of fuzzy rules that express the relationship of each input to the output. The performance of all developed models is tested by estimating mean absolute percentage error (MAPE) and paired two-tailed *t* test.

Keywords Fuzzy model · Extraversion · Neuroticism · Anxiety · Uncertainty

1 Introduction

Human behavior depends on number of psychological parameters, and extraversion, neuroticism, anxiety are few of them. Extraversion represents tendency to be sociable, assertive, active and directive. Neuroticism represents a tendency to exhibit poor emotional adjustment and experiences negative effect such as fear, anxiety, and impulsivity [12, 20]. Studies show that extraversion is associated with happiness, whereas neuroticism is associated with unhappiness [4, 22]. Many studies have established an association between anxiety and neuroticism [2]. Anxiety represents a 'state of arousal' caused by threat to well-being [28]. It means a condition of tension, uneasiness, threat and readiness which involves an entire organism to act and respond. 'Threat' means anticipation of pain, danger or serious interference with goal seeking activities.

Simulation of human behavior as an interdisciplinary research field has attracted the keen interest of mathematician and psychologist. In recent years, it has been extensively studied and applied in psychological research [21]. Zadeh [33] gave the notion of fuzzy set to handle the uncertainty which is caused by imprecise information and vague data. The interest of psychologist in fuzzy logic has visibly been growing since mid-1980s [1, 11, 25, 26]. Psychology is not only a field in which profound applications of fuzzy logic is anticipated, but is also very important for the development of fuzzy set theory itself [34]. Fuzzy logic allows researchers to handle the imprecision and vague inference of input data in depth and develop more reliable model for computing input–output relations [17]. Many researchers [6, 7, 13, 16, 18, 19, 29, 30] proposed integration of fuzzy logic in psychological research for more logical outcomes. Recently Devi [5] and Laifa [15]

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integrated fuzzy set theory with neural network to develop intelligent models for psychological research.

In the area of simulation of human behavior, a common modeling approach is to develop empirical models from questionnaire [9, 21, 24]. However, databases related to the parameters that control human behavior are too imprecise and vague to be described by random measures. Hence, prediction of personality can be deemed as an ambiguous endeavor and fuzzy modeling provides a mean to account for this ambiguity and uncertainty [8, 25, 26].

The uncertainty which is caused by imprecision and vague data is hard to deal using probability theory as many researchers [3, 10, 11, 13, 31] promoted fuzzy modeling for the simulation of human behavior and fuzzy logic was used to process qualitative variables to represent

personality to give systematic knowledge of human personality. Earlier few models of personality traits were developed that included extroversion, neuroticism, sensitive, realistic, selfish, hostile and fuzzy logic based adaptive model of emotions [8, 23, 27].

The purpose of this study is to develop Mamdani fuzzy rule-based models to get standard scores of neuroticism and extroversion from respective raw scores. Here, the scores of neuroticism and extraversion that are obtained using questionnaire are referred as raw scores. These standard scores of neuroticism and extraversion are used as inputs in another Mamdani fuzzy rule-based model that predicts the anxiety of the participants. Even though fuzzy modeling methods have been studied for decades, very few studies based on fuzzy modeling are found in the

Fig. 1 Flow-chart of overall process of development and analysis of the models

study of psychological parameters. Novelty of this paper is that it proposes a novel fuzzy rule-based model to convert raw scores to standard scores of neuroticism and extraversion. Enhanced standard scores of neuroticism and extraversion that are obtained using fuzzy models are used in another fuzzy model as input to enhance the accuracy in the prediction anxiety of the participants. The process begins with collection of raw data for neuroticism and extraversion using Maudsley personality inventory (MPI) [9] and Sinha's comprehensive anxiety test (SCAT) [24]. The whole process is illustrated in Fig. 1. The accuracy of the proposed models is tested in terms of mean absolute percentage error (MAPE). Paired two-tailed t test and Pearson's correlation coefficients are used in this study to verify the performance of developed fuzzy rule-based models and to confirm strong association between neuroticism, extraversion and anxiety.

2 Fuzzy inference systems

Fuzzy inference system (FIS) implements human experiences and preferences using membership functions and fuzzy rules. An FIS consists of different processes of fuzzification, creation of knowledge base in form of if-then rules, inferencing and defuzzification. There are two major types of fuzzy system, Mamdani and Sugeno [32]. Sugeno FIS uses the rules of the type "If x is A_1 and y is B_1 , then z is $f(x, y)$ ". Since Sugeno FIS does not use output membership function, it needs no defuzzification process. Crisp result is obtained using weighted average of the rules' consequent. Mamdani FIS is the most commonly used fuzzy rule-based model because of its inherent characteristic of handling nonlinear relationship between inputs and output. Another advantage of Mamdani FIS is its expressive power and interpretable rule consequents while loss of interpretability is observed in Sugeno FIS. The block diagram of Mamdani FIS is given in Fig. 2 that involves following components [14].

2.1 Fuzzification

This is the process to convert the crisp input to a linguistic variable using the membership function (MF) of the fuzzy sets. Selection of MF depends upon the nature of the problem to be solved using fuzzy rule-based modeling. Gaussian and triangular MFs perform well and better than other types of MFs and are extensively used in fuzzy rule-based models. Zhao and Bose [35] compared the performance of various types of MFs and concluded that triangular MF is superior to any other MF. Triangular MFs are easy to implement and have low computational complexity. Because of aforesaid reasons, we have used triangular MFs in the present study.

2.2 Fuzzy inference

Fuzzy inference is the collection of if-then-type rules. Using fuzzy inference, all if-then-type fuzzy rules converts the fuzzy input to the fuzzy output. In the present study min-max method is used for fuzzy reasoning. Figure 3 shows the inference process for the following two rules:

Rule1: If x is A_1 and y is B_1 , then z is C_1 .

Rule2: If x is A_2 and y is B_2 , then z is C_2 .

2.3 Defuzzification

This converts the fuzzy output of the inference process to crisp using membership functions used in the process of fuzzification. In the present study, we use centroid of area (COA) defuzzification method.

3 Method

3.1 Participants

In the present study, 22 M.Sc. students of final year (10 males and 12 females) of G. B. Pant University of

Fig. 2 Block diagram for a fuzzy inference system

Fig. 3 Inference process in Mamdani FIS [14]

Agriculture and Technology were chosen as the participants. All the participants were from the Department of Mathematics, Statistics and Computer Science.

3.2 Collection of raw data

The fully validated databases were created by using Maudsley personality inventory (MPI) and Sinha's comprehensive anxiety test (SCAT). These are the most comprehensive available databases for the information about neuroticism, extraversion and anxiety. In MPI questionnaire, each question was answerable in the form of yes/uncertain/no, whereas in SCAT questionnaire, each question was answerable in form of only yes/no.

3.3 Model development

Three Mamdani fuzzy rule-based models are developed. The first two models were single input single output (SISO), and the third model was multi-input single output (MISO).

3.3.1 Mamdani fuzzy rule-based model for neuroticism

The first fuzzy rule-based model is developed to convert raw score of neuroticism (x) to standard score of neuroticism (x'). MPI which is considered the most validated

database was used to collect raw data for neuroticism. Five triangular membership functions (A1–A5) and four triangular membership functions (B1–B4) were used for x and x' (Fig. 4) to linguistic representation of raw and standard score of neuroticism with universe of discourse $[0, 40]$ and $[30–60]$, respectively.

Table 1 represents the rule base used in model for neuroticism.

3.3.2 Mamdani fuzzy rule-based model for extroversion

The second fuzzy rule-based model is developed to convert raw score of extroversion (y) to standard score of extroversion (y'). Again MPI questioner was used to collect raw data for extroversion. Five triangular membership functions (C1–C5) and four triangular membership functions (D1–D4) were used for y and y' (Fig. 5) to represent raw score and standard score of extroversion linguistically. Universe of discourse for y and y' is taken as $[10, 40]$ and $[30–65]$, respectively.

Table 2 represents the rule base used in model for extroversion.

Standard scores for both neuroticism and extroversion were obtained by using min–max method for fuzzy inferencing and centroid method for defuzzification.

Fig. 4 Fuzzy sets for raw score (x) and standard score (x') for neuroticism

Table 1 Rule base for neuroticism

	B1	B2	B3	B4
A1	X	X	X	X
A2	X	X	X	X
A3	X	X	X	X
A4		X	X	X
A5			X	X

Table 2 Rule base for extroversion

	D1	D2	D3	D4
C1	X	X		
C2	X	X	X	
C3		X	X	
C4		X	X	X
C5			X	X

3.3.3 Mamdani fuzzy rule-based model for anxiety

The third fuzzy rule-based model is developed to predict the anxiety level of the participants taking standard scores of neuroticism and extroversion from fuzzy models of neuroticism and extroversion (Sects. 3.3.1 and 3.3.2) as input parameters. Observing minimum and maximum value of standard score of both neuroticism and extroversion from Table 3, universe of discourse for both standard scores of neuroticism and extroversion is redefined as [45, 50] and [40, 60], respectively. Four triangular membership functions (SB1–SB4) and (SD1–SD4) which are shown in Fig. 6a are used for standard scores of neuroticism and extroversion with redefines universe of discourse. This model uses for fuzzy sets (L, M, H, E) for anxiety level with triangular membership functions which are shown in Fig. 6b with universe of discourse [0, 60].

With the knowledge of experts, the following rule base (Table 4) is constructed for this model to predict anxiety

Fig. 5 Fuzzy sets for raw score (y) and standard score (y') of extroversion

Table 3 Raw scores and standard scores of neuroticism, extroversion by MPI and fuzzy method

Raw score of neuroticism	MPI scores of neuroticism	Standard score of neuroticism by fuzzy method	Raw score of extroversion	MPI score of extroversion	Standard score of extroversion by fuzzy method
30	57	49.563	23	42	42.1182
10	37	47.5	32	57	49.3542
04	31	47.5	16	31	34.9424
08	35	47.5	36	63	49.7085
15	42	47.5	24	44	42.3944
15	42	47.5	22	41	41.6174
19	46	47.5	32	57	49.3542
10	37	47.5	30	53	46.2621
31	58	49.5333	26	47	42.5906
29	56	49.4696	30	53	46.2621
22	59	47.5	32	57	49.3542
27	54	48.8775	22	41	41.6174
10	37	47.5	30	53	46.2621
07	34	47.5	30	53	46.2621
28	55	49.2461	22	41	41.6174
34	61	49.2239	25	45	42.5
18	45	47.5	32	57	49.3542
11	38	47.5	27	49	42.8552
24	51	47.5	24	44	42.3944
10	37	47.5	24	44	42.3944
18	45	47.5	12	24	32.6194
36	63	50.2773	24	44	42.3944

level of the participants taking standard scores of neuroticism and extroversion as inputs.

4 Performance and statistical analysis

The performance of any prediction model is measured in terms of error involved in predicted outputs. Less error implies better accuracy in predicted outputs and confirms the goodness of the model. In this study, we have used the following expression for mean absolute percentage error (MAPE) to confirm the better performance of developed models than conventional models of MPI and SCAT.

$$\text{MAPE} = \frac{1}{n} \sum_{i=1}^n \left| \frac{\hat{o}_i^p - o_i^t}{o_i^t} \right| \times 100$$

Here, $\hat{o}_i^p$ and o_i^t are the targeted and predicted outputs, respectively. To compare the outputs of developed models with conventional models more rigorously, the standard scores of both neuroticism and extroversion are obtained using fuzzy method as shown in Table 3 and the predicted anxiety of the participants using SCAT and fuzzy method in Tables 5.

Association between actual and predicted level of neuroticism, extraversion and anxiety of the participants is measured using following Pearson's correlation coefficient.

$$r = \frac{n(\sum xy) - \sum x \sum y}{\sqrt{[n \sum x^2 - (\sum x)^2][n \sum y^2 - (\sum y)^2]}}$$

From Table 6a and b, correlation coefficients ($r=0.96$, $r=0.72$), ($r=-0.16$, $r=-0.11$) and ($r=-0.13$, $r=-0.09$) among the scores of neuroticism, extraversion and anxiety confirm stronger association among these parameters than that of conventional methods of MPI and SCAT.

Even though MAPE in prediction of neuroticism using fuzzy method (2.25) is slightly higher than that of MPI method (2.01), less standard deviation in standard scores obtained by fuzzy method (0.96) confirms the out performance of develop model over conventional MPI method. Since both MAPE (0.73) and standard deviation (3.69) are reduced in prediction of extroversion using fuzzy method, it is confirmed that fuzzy method outperforms over conventional method in prediction of extroversion of participants. When standard scores of neuroticism and extroversion using fuzzy method were used in prediction of anxiety of the participants, nominal amount of MAPE 17.64 was observed. The results of paired two-tailed t test are presented in Table 7.

Fig. 6 **a** Redefined fuzzy sets for standard score of neuroticism, extroversion. **b** Fuzzy sets for anxiety

Table 4 Rule base for anxiety

SD1		SD2			SD3			SD4					
SB1						M		H	M		H		
SB2	L	M	L	M	H	L	M		H	L		M	H
SB3	L	M	L	H		L	M	H	E	L	M	H	E
SB4			M	H		L	M	H	E	L	M	H	E

Even though no significant difference is observed in outputs using conventional and fuzzy methods, proposed models produce more rational results than conventional method. The graph of anxiety of the participants is depicted in Fig. 7.

5 Conclusion

The present study proposes Mamdani fuzzy rule-based models to convert raw score of neuroticism and extroversion to their respective standard scores. This study also

proposes Mamdani fuzzy rule-based model for prediction of anxiety of the participants using standard scores of neuroticism and extroversion which are obtained from fuzzy methods.

Fuzzy set theory has been proved as an ideal tool to cope the uncertainty, as the participants are sometime biased during answering the psychological questioner or inventory and it leads the imprecision in data. The proposed models are knowledge-driven predictive models that are not very common in psychological research, but can be very useful to overcome subjective indistinctness

Table 5 Predicted anxiety of the participants using SCAT and fuzzy method

Participant	Predicted anxiety	
	SCAT method	Fuzzy rule-based method
S1	32	30
S2	5	27.2903
S3	18	27.531
S4	10	27.4719
S5	15	27.2903
S6	23	27.2903
S7	14	27.2903
S8	13	27.2903
S9	50	30
S10	12	30
S11	22	27.2903
S12	25	30
S13	06	27.2903
S14	10	27.2903
S15	25	30
S16	44	30
S17	36	27.2903
S18	14	27.5162
S19	15	27.2903
S20	02	27.2903
S21	04	26.6993
S22	59	30

and doubts in psychological research to a certain degree. The major advantage of the develop models is that it enables the use of uncertainty measures to quantify the ambiguity associated with prediction of psychological parameters. Statistical analysis (two-tailed *t* test and correlation coefficients) also confirms the outperformance of proposed fuzzy rule-based model and their ability to establish stronger relationship among the psychological parameters than conventional methods of MPI and SCAT. The potential use of the presented models includes accurate classification of the participants in extraversion and neuroticism in rapid assessment of their anxiety.

Table 6 Correlation coefficient analysis of scores of neuroticism, extroversion and anxiety obtained using (a) MPI and SCAT methods, (b) fuzzy rule-based models

<i>N</i> =22	Neuroticism (MPI)	Extroversion (MPI)	Anxiety (SCAT)
(a)			
Neuroticism (MPI)	1.00		
Extroversion (MPI)	−0.11	1.00	
Anxiety (SCAT)	0.72	−0.09	1.00
(b)			
Neuroticism (MPI)	1.00		
Extroversion (MPI)	−0.16	1.00	
Anxiety (SCAT)	0.96	−0.13	1.00

Table 7 Paired two-tailed *t* test analysis

	Neuroticism		Extroversion		Anxiety	
	MPI method	Fuzzy method	MPI method	Fuzzy method	SCAT method	Fuzzy method
Mean	46.36	48.12	47.27	44.27	20.63	28.63
SD	10.06	0.96	9.15	3.69	15.26	1.29
MAPE	2.01	2.25	0.82	0.73	–	17.64
<i>t</i> Value	0.39		0.04		0.023	

Fig. 7 Predicted anxiety of the participants using SCAT and fuzzy method

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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