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Comparative evaluation of Mamdani and Takagi-Sugeno fuzzy systems for predicting peripheral vascular resistance from photoplethysmogram signals using Persian medicine pulsology

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ABSTRACT

Objective To perform a comparative evaluation of Mamdani and Takagi-Sugeno (TS) fuzzy inference systems for predicting peripheral vascular resistance from photoplethysmogram (PPG) signals, incorporating diagnostic parameters from Persian medicine (PM) pulsology.

Methods Both fuzzy inference systems were implemented in MATLAB R2021b and validated using leave-one-out cross-validation (LOOCV) on clinical PM pulse diagnostic data collected from 35 healthy volunteers. The dataset included pulse frequency scale (1 – 6) and weakness scale (1 – 4) alongside corresponding PPG-derived peripheral vascular resistance indices (range: 0.019 – 0.983). The Mamdani system (with 35 rules) was designed using trapezoidal and triangular membership functions, a singleton fuzzifier, a product inference engine, and a centroid defuzzifier. The TS system (with 6 rules) was configured as a first-order model with Gaussian input membership functions. System performance was quantitatively evaluated using mean absolute error (MAE), root mean square error (RMSE), and the coefficient of determination (R^2). Statistical significance of performance differences was assessed using a paired t test.

Results The Mamdani inference system showed much higher prediction accuracy than the TS system. Comparative analysis revealed a substantial advantage for the Mamdani system (MAE = 0.007 63 ± 0.001 20, RMSE = 0.008 58 ± 0.001 50, R^2 = 0.998 40 ± 0.000 80) over the TS system (MAE = 0.015 40 ± 0.002 10, RMSE = 0.022 48 ± 0.002 80, R^2 = 0.989 20 ± 0.001 50). A paired t test comparing the absolute errors of the 35 LOOCV folds confirmed statistical significance [$t(34) = 5.07$, $P < 0.001$].

Conclusion The findings suggest the potential suitability of the Mamdani system for certain precision-oriented analytical tasks. Both systems exhibit practical utility for integrative medicine diagnostics and wearable health-monitoring applications for healthy individuals, enabling a modern computational translation of PM pulsology.

1 Introduction

Recent advances in computational medicine have highlighted the role of intelligent systems in integrating traditional diagnostic methods with modern technologies. Among these, Persian medicine (PM) pulsology, a centuries-old system based on multidimensional pulse analysis has gained renewed attention for

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complementing conventional cardiovascular assessments [1-3]. Photoplethysmography (PPG) enables noninvasive hemodynamic monitoring via an optical sensor [4, 5], and the PPG waveform encodes key hemodynamic information, including peripheral vascular resistance [6, 7]. However, the fusion of PM pulsology and PPG faces several key challenges. PM diagnostics are subjective and depend heavily on practitioner expertise [8-11]; automated PPG interpretation remains incomplete [12, 13]; and a unified framework is lacking, as existing studies focus separately on PM classification [1, 11, 14, 15] or PPG feature extraction [16-19]. Fuzzy inference systems can address these challenges through graded membership functions that accommodate subjective pulse descriptors such as "weak" or "strong" [20-22]. Both the Mamdani model, known for its interpretable rule structure, and the Takagi-Sugeno (TS) model, recognized for its adaptive functional consequences, are promising for complex physiological signal analysis [23, 24].

Previous studies have demonstrated the feasibility of Mamdani-type fuzzy systems for estimating PPG features from PM pulse parameters [25-28]. However, these implementations lacked formal stability analysis and systematic performance comparisons between Mamdani and TS architectures. Although the Mamdani versus TS debate has been explored in other domains [29, 30], no dedicated comparison exists for PM-PPG applications.

This study pioneers the application of TS fuzzy inference in PM pulsology beyond the exclusive use of Mamdani models, introduces guaranteed stability modeling absent in prior works, and establishes quantitative correlations between PM pulse parameters (e.g., pulse weakness and frequency) and PPG-derived peripheral vascular resistance. The key innovation is a stable fuzzy framework with bounded outputs. Therefore, this study performs a comparative evaluation of Mamdani and TS fuzzy inference systems for predicting peripheral vascular resistance from PPG signals using PM pulsology.

2 Materials and methods

The methodology of this study, shown in Figure 1, was designed to evaluate the performance of TS and

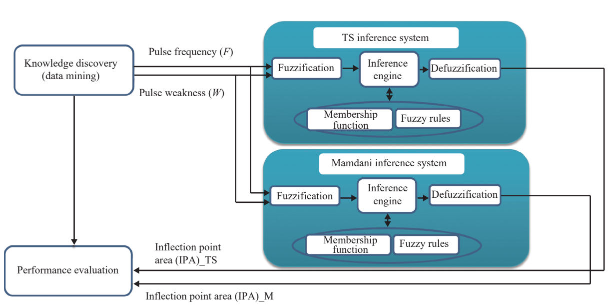

Figure 1 The flowchart of performance analysis of Mamdani and TS systems for predicting the inflection point area (IPA) index by PM pulsology

Mamdani fuzzy systems in estimating peripheral vascular resistance from pulse frequency and pulse weakness parameters of PM. The TS system is described and presented in this study, while the Mamdani system was previously used in reference [27].

Several factors motivate the need for fuzzy systems in this context. First, the interpretation of pulse findings by physicians involves subjective experience and analysis, which are prone to errors. Second, the training of PM students also introduces variability in pulse assessment. Moreover, inference based on a large number of pulse rules is inherently complex. Fuzzy systems offer a suitable framework to manage these challenges [25, 28]. Consequently, it is necessary to evaluate the performance quality and error magnitude of different fuzzy systems to select the most appropriate one for a given study. Such evaluation requires a set of actual data, corresponding predicted data, and a performance metric that quantifies how closely the predicted values approximate the actual values.

2.1 Preparing the conditions for designing fuzzy systems

To design a fuzzy system for estimating peripheral vascular resistance using PM pulse frequency and pulse weakness, a peripheral vascular resistance index was first derived from the PPG signal. The preprocessing procedure consisted of the following steps. The area under the PPG curve within a single cardiac cycle was defined as the pulse area. The pulse area was divided into two parts at the dicrotic notch, as shown in Figure 2.

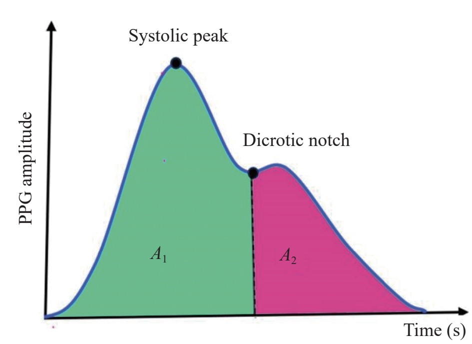

Figure 2 IPA ratio with area division A_2 by A_1

The ratio of the two areas A_1 and A_2 shown in Figure 2 is defined as the total peripheral vascular resistance index, given by Equation (1) and referred to as the IPA ratio [16]:

$$\text{IPA} = \frac{A_2}{A_1} \tag{1}$$

Data were collected at the Ahmadiyeh Persian Medicine Clinic, Tehran University of Medical Sciences, Tehran, Iran, from June 1, 2024 to October 31, 2025. Inclusion criteria for participants were aged between 7 and 69 years, with no known history of cardiovascular disease, and not taking any medication affecting heart rate or vascular tone. All participants (or their legal guardians) provided written informed consent before data collection, in accordance with a protocol approved by the Ethics Committee of Payame Noor University (IR.PNU.REC.1403.685).

The collected data included pulse frequency, pulse weakness, and PPG waveforms, all recorded by a PM specialist. Because the recorded pulse strength was predominantly low (i.e., most pulses were classified as weak), the variable was labeled "pulse weakness" rather than "pulse strength". Consequently, a decrease in pulse weakness corresponds to an increase in pulse strength, and vice versa. The total peripheral vascular resistance index data were normalized using Equation (2) to reduce computational errors:

$$x_{\text{new}} = \frac{x_{\text{old}} - x_{\min}}{x_{\max} - x_{\min}} \tag{2}$$

where x_{old} is the original data, $x_{\max}$ and $x_{\min}$ are the maximum and minimum values in the dataset, respectively, and x_{new} is the normalized data. Normalization reduces scaling-related noise but does not artificially inflate correlations, as the original unnormalized trends remain consistent.

The variables are named as follows: pulse frequency, pulse weakness, and total peripheral vascular resistance index (IPA). These data are given in Table 1.

Table 1 General specifications of pulse frequency, pulse weakness, and IPA for healthy volunteers

Variable	Max	Min	Mean	Standard deviation (SD)
Pulse frequency (F)	6.000	1.000	3.447	1.477
Pulse weakness (W)	4.000	1.000	2.382	1.029
IPA	0.983	0.019	0.366	0.225

The steps of designing a stable fuzzy system with two inputs (F, W) and one output (IPA) are as follows.

First, fuzzy sets are defined to cover the input and output spaces. Specifically, fuzzy sets for pulse frequency (F) are defined on the interval [1, 6]. Fuzzy sets for pulse weakness (W) are defined on the interval [1, 4]. Fuzzy sets for the output (peripheral vascular resistance index IPA) are defined on the interval [0, 1]. Next, fuzzy if-then rules are created using input-output data. For each input-output triplet $\left(F^l, W^l; \text{IPA}^l\right)$, the corresponding membership values in the fuzzy sets are determined.

To ensure stability conditions, the following requirements are imposed. First, regarding completeness, a fuzzy set A_i is considered complete if Equation (3) holds:

$$\forall x_i \in [\alpha, \beta] \Rightarrow \mu_{A_i}(x_i) \neq 0 \tag{3}$$

In other words, for every input value within the fuzzy set's range, the membership function value is non-zero. Second, regarding normality, a fuzzy set A_i is normal if Equation (4) holds:

$$\exists x_i | \mu_{A_i}(x_i) = 1 \tag{4}$$

In other words, there exists at least one point in the fuzzy set where the membership function equals one. Third, regarding consistency, a set of fuzzy if-then rules is consistent if no two rules share the same antecedent (if-part) but have different consequents (then-part).

In this study, "guaranteed stability" refers to bounded-input bounded-output (BIBO) stability. Specifically, for any input values within the defined ranges ($F \in [1, 6]$; $W \in [1, 4]$), the fuzzy system's output (IPA) will always remain within the predefined output interval [0, 1]. This property is ensured by using complete, normal, and consistent fuzzy sets, as defined in Equations (3) and (4).

2.2 Mamdani fuzzy system

As mentioned in previous study [27], 35 fuzzy rules were formulated based on the defined fuzzy sets and membership functions. The Mamdani fuzzy system was implemented in MATLAB R2021b using these 35 rules, with trapezoidal and triangular membership functions, a singleton fuzzifier, a product inference engine, and a centroid defuzzifier. This system is stable, with input ranges of pulse frequency [1, 6], pulse weakness [1, 4], and an output (IPA) range [0, 1]. These 35 rules were derived directly from expert knowledge provided by a certified PM practitioner, based on established clinical relationships between pulse parameters (frequency and strength) and peripheral vascular resistance (note that pulse weakness is inversely related to pulse strength). The rules were manually formulated rather than automatically extracted from the dataset, thereby ensuring clinical interpretability and face validity.

In this Mamdani fuzzy system, peripheral vascular resistance decreases as both pulse frequency and pulse weakness decrease, and increases as both pulse frequency and pulse weakness increase.

2.3 TS fuzzy system

In a TS fuzzy system, the output of each rule is a first-order polynomial of the input variables. Specifically, consider a TS fuzzy system with r rules, n inputs, and one output. The L-th rule (L = 1, 2, ..., r) is given by Equation (5) [2, 30]:

$$\begin{aligned} &\text{Rule } L: \text{if } x_1 \text{ is } A_1^L, \text{ and } x_2 \text{ is } A_2^L, \text{ and} \ldots, x_n \text{ is } A_n^L, \text{ then} \\ &\qquad y^L = \alpha_0^L + \alpha_1^L x_1 + \ldots + \alpha_n^L x_n \end{aligned} \tag{5}$$

where in $L = \{1, 2, \ldots, r\}$, $\alpha^L = \left\{\alpha_0^L, \alpha_1^L, \alpha_2^L, \ldots, \alpha_n^L\right\}$ are the consequent parameters. The fuzzy sets for each input are defined as:

$$A_i = \{A_i^1, A_i^2, ..., A_i^L\}$$

Given an input vector $x = (x_1, x_2, ..., x_n)^T$, the overall output $f(x)$ is the weighted average of the rule outputs:

$$f(x) = \sum_{L=1}^{r} y^L \overline{w}^L \tag{6}$$

where $w^L = \prod_{i=1}^{n} \mu_{A_i^L}(x_i)$, $\overline{w}^L = \dfrac{w^L}{\sum_{L=1}^{r} w^L}$.

In this study, the membership functions were chosen to be Gaussian, as expressed in Equation (7) [2]:

$$\mu_{A_i}(x_i) = e^{-\frac{1}{2}\left(\frac{x_i - m_i}{\sigma_i}\right)^2} \tag{7}$$

where σ_i and m_i are the variance and center (adjustable parameters) of the Gaussian function, respectively.

A TS fuzzy system was designed using MATLAB R2021b based on data from volunteers aged 7 to 69 years. First, fuzzy sets were defined for pulse frequency (F) on the interval [1, 6], pulse weakness (W) on [1, 4], and the IPA output on [0, 1]. Pulse frequency and pulse weakness were used as input variables, and the IPA as the output variable. Using the input-output triplets $(F^l, W^l; \text{IPA}^l)$ from the volunteers, a total of 6 rules were defined.

The TS system employed a first-order polynomial consequent for each rule, allowing each rule to define a local linear model over a specific region of the input space. Consequently, the model's expressiveness and adaptability are achieved through the combination of these few local linear functions and the Gaussian antecedent membership functions, rather than through a large number of independent linguistic rules. This characteristic of TS systems typically leads to a more compact rule base compared to the Mamdani architecture, which requires a separate linguistic rule for each distinct input-output mapping [30]. Therefore, while the Mamdani system required 35 rules to linguistically encode expert knowledge, the TS system achieved a comparable mapping of the input-output relationship with only 6 locally linear rules.

The surface diagram illustrating the three-dimensional relationship between the inputs (pulse frequency and pulse weakness) and the output (IPA) of the TS fuzzy system is shown in Figure 3.

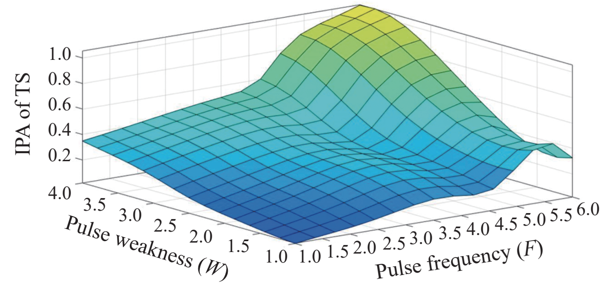

Figure 3 Three-dimensional representation of the TS fuzzy inference system based on the two input variables pulse frequency (F) and pulse weakness (W), and the output total peripheral vascular resistance index IPA

2.4 Performance evaluation

Performance evaluation was primarily based on prediction errors. Visual analysis of the results was also performed to support the quantitative assessment.

To evaluate prediction accuracy, the following metrics were calculated: absolute error (AE), mean absolute error (MAE), relative error (RE), mean square error (MSE), root mean square error (RMSE), and coefficient of determination (R^2). These metrics are defined in Equations (8) – (13), respectively [29, 31].

$$\text{AE}^i = \left|\text{IPA}_O^i - \text{IPA}_{\text{FIS}}^i\right| \tag{8}$$

$$\text{MAE} = \frac{1}{N}\sum_{i=1}^{N}\left|\text{IPA}_O^i - \text{IPA}_{\text{FIS}}^i\right| \tag{9}$$

$$\text{RE}^i = \frac{\left|\text{IPA}_O^i - \text{IPA}_{\text{FIS}}^i\right|}{\left|\text{IPA}_O^i\right|} \tag{10}$$

$$\text{MSE} = \frac{1}{N}\sum_{i=1}^{N}\left(\text{IPA}_O^i - \text{IPA}_{\text{FIS}}^i\right)^2 \tag{11}$$

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\text{IPA}_O^i - \text{IPA}_{\text{FIS}}^i\right)^2} \tag{12}$$

$$R^2 = 1 - \left\{\frac{\sum_{i=1}^{N}\left(\text{IPA}_O^i - \text{IPA}_{\text{FIS}}^i\right)^2}{\sum_{i=1}^{N}\left(\text{IPA}_O^i - \overline{\text{IPA}}_O^i\right)^2}\right\} \tag{13}$$

where IPA_O^i and $\text{IPA}_{\text{FIS}}^i$ are the i-th observed and predicted IPA values, respectively, and N is the total number of data points ($N = 35$).

2.5 Statistical analysis

Statistical analyses were performed using MATLAB R2021b and Microsoft Excel. To robustly estimate prediction accuracy, we calculated the MAE, RMSE, and R^2 [defined in Equations (8) – (13)] using leave-one-out cross-validation (LOOCV), which was necessitated by the limited sample size ($N = 35$). In each LOOCV fold, 34 samples were used for training and the remaining one for testing; this process was repeated 35 times so that each sample served once as the test set. All reported metrics are presented as mean ± SD across the 35 LOOCV folds.

To statistically compare the prediction errors of the Mamdani and TS systems, a paired two-tailed t test was performed on the absolute prediction errors obtained from the 35 LOOCV test folds.

3 Results

The dataset from 35 healthy volunteers included pulse frequency scale (1 – 6) and weakness scale (1 – 4) along with corresponding PPG-derived peripheral vascular resistance indices (range: 0.019 – 0.983).

3.1 AE

The AE results show that both the TS fuzzy system (6 rules) and the Mamdani fuzzy system (35 rules) predict IPA values for 35 healthy volunteers with an error of less than 0.08. Visual analysis of the AEs confirmed that both systems—using pulse frequency and pulse weakness as inputs and IPA as the output—performed satisfactorily within the defined input ranges. The Mamdani fuzzy system achieves a lower absolute error in predicting IPA than the TS fuzzy system. Specifically, the absolute errors of the Mamdani system were lower than those of the TS system for most volunteers, with only a few exceptions (Figure 4).

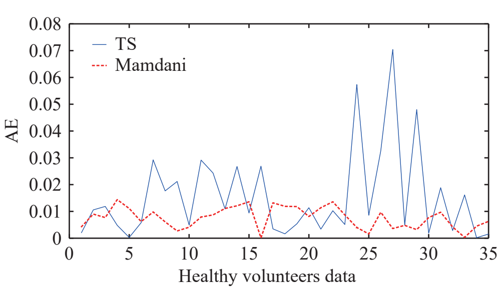

Figure 4 Comparison of AEs of Mamdani and TS systems for predicting the total peripheral vascular resistance

3.2 RE

The RE results for the two fuzzy systems Mamdani and TS for predicting IPA values in 35 healthy volunteers are shown in Figure 5. As observed with AE, the Mamdani system achieved a substantially lower relative error in predicting IPA than the TS system. This pattern held for most volunteers, with only a few exceptions.

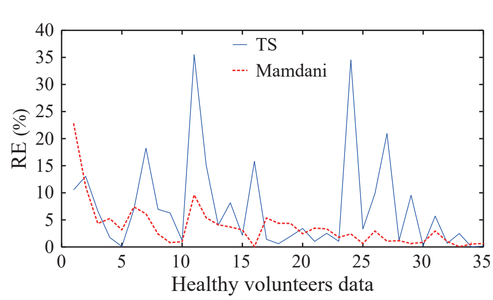

Figure 5 Comparison of REs of Mamdani and TS systems for predicting the total peripheral vascular resistance

3.3 Regression

Figure 6 shows the regression plots for Mamdani and TS fuzzy systems for 35 healthy volunteers. Visual analysis indicated that, although the TS system yielded better IPA predictions for some volunteers, the Mamdani system was more accurate for the majority of volunteers.

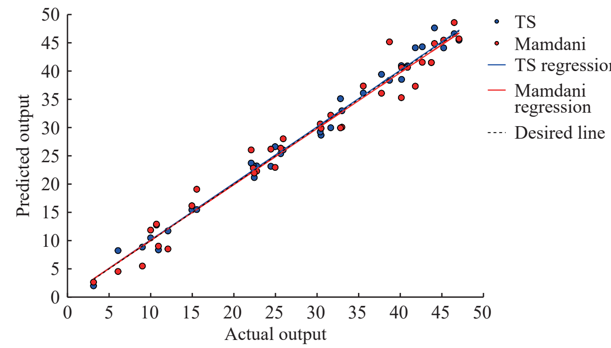

Figure 6 Comparison of regressions of Mamdani and TS systems for predicting the total peripheral vascular resistance

3.4 Simulation results

The simulated results for the two fuzzy inference systems Mamdani and TS for estimating the IPA index from PM pulse parameters can be seen in Figure 7, which illustrates the predicted versus actual IPA values for both systems.

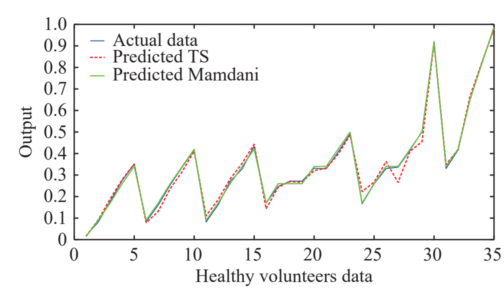

Figure 7 Comparison of predictions of Mamdani and TS systems for the total peripheral vascular resistance

All performance metrics (MAE, RMSE, and R^2) reported in Table 2 represent the results obtained across all LOOCV folds.

Table 2 LOOCV performance metrics for Mamdani and TS fuzzy systems in IPA prediction (mean ± SD)

Fuzzy system	MAE	RMSE	R^2
Mamdani	0.007 63 ± 0.001 20	0.008 58 ± 0.001 50	0.998 40 ± 0.000 80
TS	0.015 40 ± 0.002 10	0.022 48 ± 0.002 80	0.989 20 ± 0.001 50

A paired t test comparing the absolute errors of the 35 LOOCV folds confirmed statistical significance [t (34) = 5.07, $P < 0.001$].

4 Discussion

4.1 Mamdani's performance and physiological basis

There are key differences in the performance and usability of the two fuzzy systems, Mamdani and TS. The Mamdani fuzzy system produces outputs by aggregating multiple fuzzy rule outputs using centroid defuzzification [20, 21, 27], whereas each rule in the TS fuzzy system contributes a weighted linear function to the overall output [2, 29, 30]. The results of this study demonstrate that the Mamdani fuzzy system outperformed the TS system across all key metrics. The LOOCV ensured reliable performance estimation despite the limited sample size (N = 35); all metrics are aggregated cross-validation results. This superior performance is evidenced by significantly lower errors. The Mamdani system achieved a MAE of 0.007 63 and a RMSE of 0.008 58, compared to 0.015 40 and 0.022 48 for the TS system, indicating higher predicting precision. Furthermore, the Mamdani system exhibited a near-perfect R^2 value of 0.998 40, suggesting that its rules align almost perfectly with the observed physiological relationships. Several factors explain this superior performance. The strong physiological correlation between PM pulse parameters (frequency and weakness) and peripheral vascular resistance is well documented in PM literature. The linguistic rule-based architecture of the Mamdani system directly encodes expert diagnostic logic, minimizing model error. Additionally, the centroid defuzzification method employed in the Mamdani system minimizes output variability, a critical feature for medical applications where small errors can significantly impact clinical decisions.

The Mamdani system's 35 transparent rules, which utilize interpretable membership functions (e.g., triangular and trapezoidal), allow physicians to trace how input variables are mapped to IPA estimates. This aligns perfectly with Persian medicine's emphasis on interpretable diagnostics. In contrast, the TS system's crisp linear outputs, despite their computational efficiency, obscure the underlying physiological logic, making it less suitable for clinical validation. The Mamdani system also demonstrated a critical advantage: bounded input-output stability. This feature, ensured by our formal analysis and supported by prior research [27], guarantees that all predictions remain within physiologically plausible ranges. Furthermore, unlike the TS model, which exhibited disturbances during the early design stages, the Mamdani architecture was entirely free of such instabilities [29].

4.2 Stability and interpretability analysis

This study's contributions are clearly positioned by a direct comparison with key recent works in PPG analysis and computational PM. Our work moves decisively beyond proof-of-concept demonstrations to provide a rigorous, stability-aware architectural comparison. In comparison to foundational PM-PPG studies employing Mamdani-type fuzzy systems, such as those estimating systolic area [25] or peripheral vascular resistance [27], our research introduces two critical advancements. First, we provide the first head-to-head performance evaluation against the TS architecture for this specific physiological prediction task. Second, our implemented Mamdani model achieves superior quantitative accuracy (R^2 = 0.998 40, MAE = 0.007 63), exceeding the error thresholds (e.g., MAE < 0.05 [28] or max error 0.01 [27]) reported in these prior single-architecture studies, while formally guaranteeing system stability.

Our findings contribute to the broader debate on fuzzy system selection. In domains like traffic calibration, TS systems have shown superiority for adaptive, real-time control [29]. Conversely, in medical diagnostics, the interpretability of Mamdani systems is often paramount [30]. Our results provide strong, domain-specific evidence. For translating subjective PM diagnostics into quantitative physiological estimates, the Mamdani architecture is not only more interpretable but can also achieve higher predictive accuracy than a first-order TS model.

4.3 Limitations and future study

Several limitations should be acknowledged. The study's results are based on data from 35 healthy volunteers; therefore, the system's performance on pathological cases, such as individuals with cardiovascular diseases, requires further validation. Additionally, while the Mamdani system's defuzzification process carries a higher computational load than the TS system's weighted averaging, this difference is negligible for offline clinical analysis. Furthermore, the current study was conducted exclusively on healthy volunteers. Therefore, the system's diagnostic performance in patients with cardiovascular disorders has not yet been established and requires future investigation.

For future research, two primary directions are proposed. First, hybrid systems should be developed that combine the interpretability of the Mamdani framework with the computational efficiency of the TS model, creating architectures suitable for real-time monitoring applications such as wearable PPG devices. Second, the system's performance must be validated on pathological cases, particularly patients with vascular disorders, to thoroughly assess its clinical generalizability and diagnostic robustness beyond healthy populations.

5 Conclusion

This study successfully developed a stable and interpretable fuzzy system for predicting the peripheral vascular resistance index (IPA) from PM pulse parameters. The Mamdani system emerged as the superior framework, supported by its exceptional predictive accuracy: a near-perfect R^2 value of 0.998 40 and low prediction errors (MAE: 0.007 63). This validates its precise alignment with established PM pulsology principles. Furthermore, its transparency allows physicians to examine all 35 rules to understand how specific pulse features (e.g., frequency and weakness) map to the IPA output, thereby fostering trust in artificial intelligence (AI)-assisted diagnostics. The system's inherent safety, guaranteed by bounded output stability, ensures that all predictions remain within physiologically plausible ranges. The Mamdani framework offers high accuracy and interpretability for estimating peripheral vascular resistance from PM pulse parameters in healthy individuals.

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Ethical statement

This study was approved by the Ethics Committee of Payame Noor University, Tehran, Iran (IR.PNU.REC. 1403.685). Informed consent was obtained from all individual participants included in the study.

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Author contributions

Mohammad Dehghandar: conceptualization, methodology, data curation, software, formal analysis, investigation, writing – original draft, supervision, validation, and visualization. Maryam Nikbakht: methodology, software, and data curation. Fatemeh Yousefi Nadarabadi: conceptualization, resources, supervision, project administration, and validation. All authors approved the submission and take responsibility for this manuscript.

Competing interest

The authors declare no conflicts of interest.

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基于波斯医学脉诊的光电容积描记信号预测外周血管阻力的 Mamdani 与 Takagi-Sugeno 模糊系统比较评价

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【摘要】目的 对 Mamdani 与 Takagi-Sugeno（TS）模糊推理系统在预测光电容积描记（PPG）信号所反映的外周血管阻力方面的性能进行比较评价，并整合了波斯医学（PM）脉诊中的诊断参数。**方法** 两种模糊推理系统均采用 MATLAB R2021b 实现，并基于来自 35 名健康志愿者的临床 PM 脉诊数据，采用留一法交叉验证（LOOCV）进行验证。数据集包括脉搏频率量表评分（1 – 6）和脉搏虚弱程度量表评分（1 – 4），以及相应的 PPG 衍生外周血管阻力指数（范围：0.019 – 0.983）。Mamdani 系统包含 35 条规则，采用梯形和三角形隶属函数、单点模糊化器、乘积推理引擎以及质心解模糊化器。TS 系统包含 6 条规则，配置为一阶模型，并采用高斯型输入隶属函数。系统性能通过平均绝对误差（MAE）、均方根误差（RMSE）和决定系数（R^2）进行定量评价。两种系统性能差异的统计学显著性采用配对 t 检验进行评估。**结果** Mamdani 推理系统的预测准确性明显高于 TS 系统。比较分析显示，Mamdani 系统相较于 TS 系统具有显著优势：Mamdani 系统的 MAE 为 0.007 63 ± 0.001 20，RMSE 为 0.008 58 ± 0.001 50，R^2 为 0.998 40 ± 0.000 80；而 TS 系统的 MAE 为 0.015 40 ± 0.002 10，RMSE 为 0.022 48 ± 0.002 80，R^2 为 0.989 20 ± 0.001 50。基于 35 个 LOOCV 折的绝对误差进行配对 t 检验，结果表明两种系统之间的差异具有统计学意义 [t (34) = 5.07，P < 0.001]。**结论** Mamdani 系统可能适用于某些对精度要求较高的分析任务。两种系统均显示出在整合医学诊断和可穿戴健康监测应用中的实用价值，可用于健康个体，并为波斯医学脉诊提供一种现代计算化转化路径。

【关键词】光电容积描记；模糊推理系统；外周血管阻力；波斯医学；脉诊；Takagi-Sugeno