

VITAL SIGNS-BASED ENGINEERING STUDENTS' STRESS LEVEL PREDICTION AND IMPACT ANALYSIS ON ACADEMIC PERFORMANCE USING A²RQNFIS

SWATI JOSHI

DEPARTMENT OF COMPUTER SCIENCE, BANASTHALI VIDYAPITH, RAJASTHAN, INDIA,
EMAIL: cse.swatijoshi@gmail.com

DR. SANJAY KUMAR SHARMA

DEPARTMENT OF COMPUTER SCIENCE, BANASTHALI VIDYAPITH, RAJASTHAN, INDIA,
EMAIL: skumar2.sharma@gmail.com

Abstract: For improving the engineering students' academic performance, their stress level is predicted. But, the prevailing works didn't focus on calculating engineering students' stress index based on important vital signs. Thus, vital signs-based engineering students' stress level prediction and impact analysis on academic performance using Adaptive Arctangent Rational Quadratic Neuro-Fuzzy Inference System (A²RQNFIS) are presented in this paper. Firstly, students' stress level data are taken; then, they are cleaned. Afterward, by using Density-Based Bray-curtisMatusita Spatial Dunn Hubert Clustering of Applications with Noise (DB²MSDHCAN), pattern analysis is performed. Thereafter, by employing the ErlangGompertz Kalman Filter (EGKF), temporal dynamic analysis is done. Similarly, from cleaned data, a spider plot is constructed. Next, from the plot and temporal dynamic analysis outcomes, features are extracted. Likewise, based on the vital signs, the stress index is calculated. Similarly, from Students' Academic Stress Questionnaires (SASQ), the stress score is estimated. Then, the stress level of engineering students is predicted based on the extracted features, stress index, and stress score by using A²RQNFIS. Next, by using coping strategies, stress management suggestions are provided. Similarly, by using A²RQNFIS, the academic performance of engineering students is predicted. Afterward, by using the Pearson Correlation Coefficient (PCC), correlation analysis is done. Students are highly impacted if the correlation is high. Students are less impacted if the correlation is low. As per the results, the proposed model achieves a high accuracy of 98.68%, which is superior to the prevailing techniques.

Keywords: Vital signs, Adaptive Arctangent Rational Quadratic Neuro-Fuzzy Inference System (A²RQNFIS), Density-Based Bray-curtisMatusita Spatial Dunn Hubert Clustering of Applications with Noise (DB²MSDHCAN), ErlangGompertz Kalman Filter (EGKF), Pearson Correlation Coefficient (PCC), Coping strategies, and Students' Academic Stress Questionnaires (SASQ).

1. INTRODUCTION

Usually, stress is the psychological and emotional pressure experienced by students during their academic period (Liu et al., 2024). Lack of sleep, fear of low grades, and high levels of competition may be experienced by students, which causes stress to the students (Bork & Mondisa, 2022). Similarly, stress can exacerbate other mental health issues in students (Parthiban et al., 2021). Also, engineering students experience anxiety disorders as twice much as other college students (Sergio et al., 2024). But, high stress affects the academic performance of students (Jensen & Cross, 2021). Thus, to predict the stress level of students, many Artificial Intelligence (AI) techniques are established (Morales-Rodríguez et al., 2021).

To predict the stress level of students, Machine Learning (ML) techniques like KNN, RF, decision tree, and SVM were employed in existing studies (Siddique S et al., 2021) (Geronimo et al., 2023). Similarly, for correlation analysis, some researchers employed Structural Equation Modeling (SEM) (Deng et al., 2022). Moreover, for students' academic performance prediction, ensemble-based classifiers were utilized (Siddique A et al., 2021). But, the existing studies didn't concentrate on calculating the stress index based on important vital signs. Thus, this paper proposes vital signs-based engineering students' stress level prediction and impact analysis on academic performance using A²RQNFIS.

1.1 Problem Statement

❑ None of the prevailing works concentrated on calculating engineering students' stress index based on four important vital signs, namely temperature, SpO₂, heartbeat, and respiratory.

- ❑ The prevailing (Durán Acevedo et al., 2021) didn't provide any stress management suggestions to the high-stressed students.
- ❑ The relationship between stress level and academic performance was not considered in existing techniques (Balamurugan et al., 2023).
- ❑ Owing to the high volume of different students' information, complexities occurred in stress level prediction.
- ❑ Most of the existing works didn't capture the temporal changes in stress levels.

1.2 Objectives

- ◆ Vital signs are taken from students while studying; then, the stress index is calculated by using A²RQNFIS.
- ◆ Coping strategies are developed to provide stress management suggestions.
- ◆ PCC is utilized for correlation analysis, thereby analyzing the stress impact on academic performance.
- ◆ DB²MSDHCAN is introduced to group the distinct student information.
- ◆ EGKF is used to capture the temporal changes in stress levels.

The paper is structured as: The existing works are described in Section 2, the proposed methodology is illustrated in Section 3, the result is conveyed in Section 4, and lastly, the proposed model is concluded in Section 5 with future scope.

2. LITERATURE SURVEY

(Durán Acevedo et al., 2021) offered a framework named Academic Stress Detection on university students. Here, to predict the stress level, the model employed K-Nearest Neighbors (KNN) and Support Vector Machine (SVM). A high success rate was obtained in the research. But, this work didn't provide any stress management suggestions to the high-stress students.

(Balamurugan et al., 2023) discovered students' stress prediction model for academic growth. Here, to identify the mental stress of students, the Random Forest (RF) algorithm was used. Likewise, the model helped administrators to assess students' abilities. But, the research didn't consider the relationship between stress levels and academic performance.

(Nijhawan et al., 2022) presented a social interactions-based stress detection framework. Here, for stress detection, the ML approaches and Bidirectional Encoder Representation from Transformers (BERT) model were utilized. A high detection rate was obtained by the model. But, this work had insufficient factors for stress analysis.

(Jiao et al., 2022) recommended a student academic performance prediction model in engineering education. Here, to predict the academic performance of engineering students, genetic programming was employed. The suggested model was better for evaluating the learning performance of students. But, it failed to capture the temporal changes of students for accurate prediction.

(Feng et al., 2022) offered an educational data mining-based students' academic performance prediction model. Here, for academic performance prediction, the Convolutional Neural Network (CNN) was utilized. Superior performance and high reliability were achieved in the research. However, this work had overfitting issues and a lack of generalizability.

3. PROPOSED METHODOLOGY

Here, to predict the stress level of engineering students, the proposed A²RQNFIS is introduced. In Figure 1, the proposed model's diagrammatic representation is displayed.

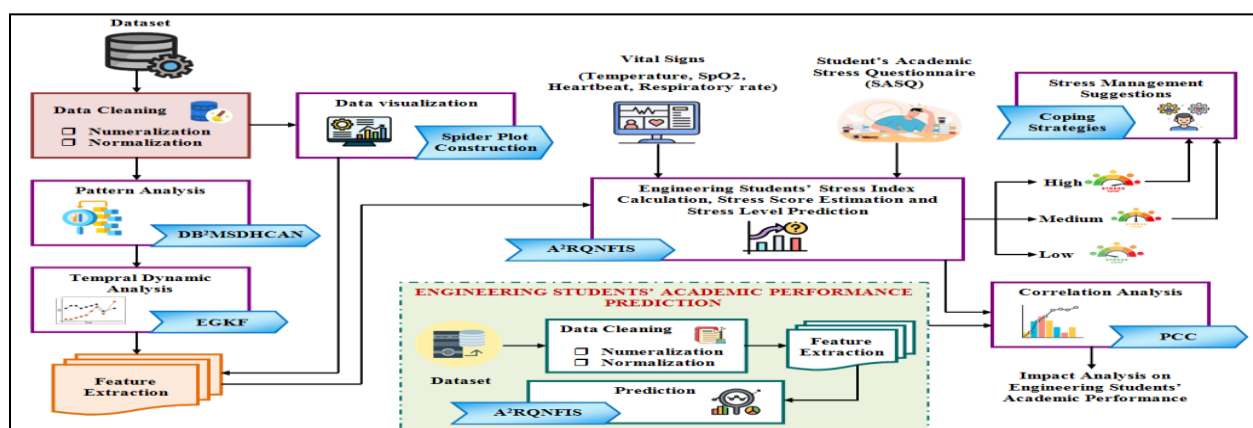


Figure 1: Diagrammatic representation of the proposed model

3.1 Dataset

Initially, to train the proposed model, the student's stress factor dataset is taken, and it is expressed as $\mathbb{S}_r^{data}$.

3.2 Data Cleaning

Next, to improve the data's quality, $\mathbb{S}_r^{data}$ are preprocessed. Initially, the string values in the $\mathbb{S}_r^{data}$ are converted into numerical values in the numeralization process and are signified as λ_ϕ . Then, by using min-max normalization, λ_ϕ are normalized.

$$N(\lambda_\phi) = \frac{\lambda_\phi - \min(\lambda_\phi)}{\max(\lambda_\phi) - \min(\lambda_\phi)} \quad (1)$$

Here, $\min(\lambda_\phi)$ and $\max(\lambda_\phi)$ specify the maximum and minimum values, respectively. The cleaned data is specified as ϕ_v .

3.3 Pattern Analysis

Next, pattern analysis is performed based on the ϕ_v by using DB²MSDHCAN. Here, based on the similar patterns of students, ϕ_v is grouped. Density-Based Spatial Clustering of Applications with Noise (DBSCAN) allows for more flexible and accurate grouping. But, the important parameters in DBSCAN are epsilon and minpts, which need to be calculated accurately. Thus, the Bray-curtis Matusita distance and Dunn Hubert index are used in DBSCAN.

Primarily, the epsilon parameter (α) is estimated by employing Bray-curtis Matusita distance, which estimates the average similarity ratio of each cluster with its most similar cluster.

$$\alpha \rightarrow \sqrt{2 \left(1 - \sum_v \sqrt{(\phi_v)(\phi_j)} \right) * \frac{\sum_v |\phi_v - \phi_j|}{\sum_v |\phi_v + \phi_j|}} \quad (2)$$

Here, γ states the constant value. Then, the clusters are formed by minpts (γ), which is estimated by using Dunn Hubert index.

$$\gamma = \frac{\phi_{in} - \phi_{out}}{\sqrt{\phi_{in} + \phi_{out}}} * \frac{\min_{vj} D(\phi_v, \phi_j)}{\max_j dia(\phi_j)} \quad (3)$$

Where, ϕ_{in} and ϕ_{out} outline the data points in the same cluster and different clusters, respectively, D shows distance, and dia signifies diameter. Then, the core point (U) that aids in identifying the clusters is estimated.

$$U = \alpha \times \gamma \quad (4)$$

Based on the (U), (α), and (γ), the cleaned data are grouped according to similar patterns of students. This grouping is continued until convergence. The grouped data is represented as G_f .

Pseudocode for DB²MSDHCAN

Input: Cleaned data (ϕ_v)

Output: Grouped data (G_f)

Begin

Initialize (ϕ_v)

For each (ϕ_v)

Estimate epsilon

$$\alpha \rightarrow \sqrt{2 \left(1 - \sum_v \sqrt{(\phi_v)(\phi_j)} \right) * \frac{\sum_v |\phi_v - \phi_j|}{\sum_v |\phi_v + \phi_j|}}$$

Form clusters

$$\gamma = \frac{\phi_{in} - \phi_{out}}{\sqrt{\phi_{in} + \phi_{out}}} * \frac{\min_{vj} D(\phi_v, \phi_j)}{\max_j dia(\phi_j)}$$

Identify clusters by core points

$$U = \alpha \times \gamma$$

Continue until convergence

End For

Obtain (G_f)

End

Next, temporal dynamic analysis is done.

3.4 Temporal Dynamic Analysis

Then, by utilizing EGKF, the temporal dynamic analysis is performed centered on G_f . Kalman Filter (KF) effectively provides timely updates. Also, poor initialization can lead to slow convergence in KF. Thus, in KF, the ErlangGompertz function is used. Initially, by using the ErlangGompertz function (ξ), the state estimate (Y_{st}) and covariance estimate (Z_{co}) are initialized:

$$\xi = v \exp^{-w \exp^{-x G_f}} * \frac{(v G_f)^{w-1} \exp^{-v G_f}}{(w-1)!} \quad (5)$$

Here, v , w , and x are the constants. Next, expected measurement ($\tilde{J}_{\bar{p}}$) and measurement residual (B_p) are predicted as,

$$\tilde{J}_{\bar{p}} = Q_p \tilde{Y}_{\bar{p}} \quad (6)$$

$$B_p = J_p - \tilde{J}_{\bar{p}} \quad (7)$$

Here, Q_p implies the measurement matrix, $\tilde{Y}_{\bar{p}}$ indicates the predicted state estimate, and J_p signifies the new measurement. Next, Kalman gain (Ka_p) is calculated. Similarly, the state estimate and covariance matrix are updated based on (B_p), which are denoted as $\tilde{Y}_p$ and Z_p , respectively. Similarly, for the next step, the state and covariance matrix are predicted, which are represented as $\tilde{Y}_{\bar{p}+1}$ and $\tilde{Z}_{\bar{p}+1}$, correspondingly. Finally, the temporal dynamic analysis outcomes are signified as $\mathcal{F}_u$.

Pseudocode for EGKF

Input: Grouped data (G_f)

Output: Temporal dynamic analysis outcomes ($\mathcal{F}_u$)

Begin

```

Initialize ( $G_f$ )
For each ( $G_f$ )
    Initialize ( $Y_{st}$ ) and ( $Z_{co}$ ) using ( $\xi$ )
     $\xi = v \exp^{-w \exp^{-x G_f}} * \frac{(v G_f)^{w-1} \exp^{-v G_f}}{(w-1)!}$ 
    Predict  $\tilde{J}_{\bar{p}} = Q_p \tilde{Y}_{\bar{p}}$ 
     $B_p = J_p - \tilde{J}_{\bar{p}}$ 
    Estimate kalman gain ( $Ka_p$ )
    Update ( $Y_{st}$ ) and ( $Z_{co}$ )
    Compute next step  $\tilde{Y}_{\bar{p}+1}$  and  $\tilde{Z}_{\bar{p}+1}$ 
End For
Obtain ( $\mathcal{F}_u$ )

```

End

Then, features are extracted from $\mathcal{F}_u$.

3.5 Data Visualization

Likewise, the data visualization is done from $\mathcal{F}_v$. Here, to visualize the distinct student information without any overlap, the spider plot is constructed and is defined as V_{plot} .

3.6 Feature Extraction

Then, from V_{plot} , features, such as Academic Pressure, Sleep Quality, Extracurricular Involvement, and Self-Efficacy are extracted, and it is indicated as F_v . Similarly, from $\mathcal{F}_u$, the features, such as academic milestones, stress variability, and exam preparation time are extracted, and it is signified as $\mathcal{X}_a$. The extracted features are considered as E_k .

3.7 Engineering Students' Stress Index Calculation, Stress Score Estimation, and Stress Level Prediction

Next, by employing A²RQNFIS, engineering students' stress index calculation, stress score estimation, and stress level prediction are performed. Adaptive Neuro-Fuzzy Inference System (ANFIS) effectively adjusts its parameters

based on new data or changes. Still, ANFIS often requires appropriate membership functions and rule bases. Thus, in ANFIS, the Arctangent Rational Quadratic membership function is employed.

3.7.1 Vital Signs-based Stress Index Calculation

Here, the vital signs, such as temperature, peripheral oxygen saturation (SpO₂), heartbeat, and respiratory rate are taken from students while studying through the wearable devices. Next, the stress index (Ω) is calculated based on the vital signs.

$$\Psi = \begin{cases} \text{if } t > 36 \ \&\& \ s > 0.95 \ \&\& \ h > 60 \ \&\& \ R > 12 & \text{low} \\ \text{if } t = 36 - 37.5 \ \&\& \ s = 0.95 - 1 \ \&\& \ h = 60 - 100 \ \&\& \ R = 12 - 20 & \text{medium} \\ \text{if } t < 37.5 \ \&\& \ s < 1 \ \&\& \ h < 100 \ \&\& \ R < 20 & \text{high} \end{cases} \quad (8)$$

Where, Ψ indicates the vital sign ranges.

$$\Omega \xrightarrow{\Psi} \begin{cases} \text{if } t = \text{low} \ \&\& \ s = \text{low} \ \&\& \ h = \text{low} \ \&\& \ R = \text{low} & \Omega = \text{low} \\ \text{if } t = \text{low} \ \&\& \ s = \text{medium} \ \&\& \ h = \text{low} \ \&\& \ R = \text{low} & \Omega = \text{low} \\ \text{if } t = \text{high} \ \&\& \ s = \text{high} \ \&\& \ h = \text{low} \ \&\& \ R = \text{high} & \Omega = \text{medium} \\ \text{if } t = \text{high} \ \&\& \ s = \text{high} \ \&\& \ h = \text{medium} \ \&\& \ R = \text{medium} & \Omega = \text{medium} \\ \text{if } t = \text{medium} \ \&\& \ s = \text{high} \ \&\& \ h = \text{high} \ \&\& \ R = \text{high} & \Omega = \text{high} \\ \text{if } t = \text{high} \ \&\& \ s = \text{high} \ \&\& \ h = \text{high} \ \&\& \ R = \text{medium} & \Omega = \text{high} \\ \vdots & \vdots \\ \text{if } t = \text{high} \ \&\& \ s = \text{high} \ \&\& \ h = \text{high} \ \&\& \ R = \text{high} & \Omega = \text{high} \end{cases} \quad (9)$$

Where, t implies temperature, s illustrates SpO₂, h denotes heartbeat, and R indicates respiratory rate.

3.7.2 SASQ-based Stress Score Estimation

Similarly, SASQ is considered; from that response, the stress score is estimated. For each questionnaire, the options like never-0, almost never-1, sometimes-2, fairly often-3, and very often-4 are considered. The values (i.e., 0 means 4, 1 means 3, 2 means 2, 3 means 1, and 4 means 0) are assigned to the options. Then, to calculate the stress score (Θ), the obtained values from the students for each questionnaire are added.

$$\Theta = \begin{cases} \text{if } \delta = (0 - 13) & \text{low stress} \\ \text{if } \delta = (14 - 26) & \text{medium stress} \\ \text{if } \delta = (27 - 40) & \text{high stress} \end{cases} \quad (10)$$

Where, (δ) is the added value.

3.7.3 Stress Level Prediction

Finally, the stress level is predicted based on the E_k , Ω , and Θ by using A²RQNFIS. The inputs E_k , Ω , and Θ are considered as μ_ϕ . In Figure 2, the A²RQNFIS diagram is shown.

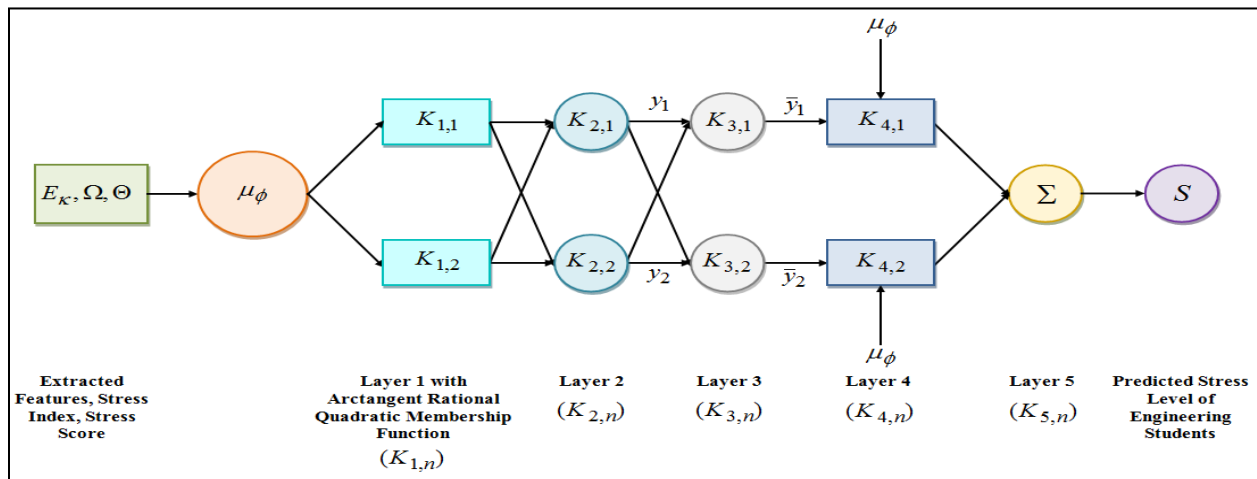


Figure 2: A²RQNFIS diagram

Fuzzification layer: Initially, each node is adjusted to a function parameter, and the membership function is the output of each node. The fuzzification layer ($K_{1,n}$) is given as,

$$K_{1,n} = \beta(\mu_\phi) \quad (11)$$

Here, β indicates the Arctangent Rational Quadratic membership function, and it is expressed as,

$$\beta(\mu_\phi) = \frac{1}{2} \frac{\arctan\left(\frac{\mu_\phi - C}{d}\right) + \frac{\pi}{2}}{\left(1 + \left(\frac{\mu_\phi - C}{d}\right)^2\right)} \quad (12)$$

Here, $\arctan$ denotes the arctangent function, μ_ϕ indicates steepness, C exemplifies the center, and d signifies the spread.

Rule layer: Here, each nodes are fixed. Similarly, firing strength is calculated for each rule. The rule layer ($K_{2,n}$) is estimated as,

$$K_{2,n} = y_n = \beta(\mu_\phi) \quad \text{where } n = 1, 2 \quad (13)$$

Where, y_n indicates the firing strength.

Normalization layer: In the normalization layer, the firing strength is normalized as follows,

$$K_{3,n} = \bar{y}_n = \frac{y_n}{\sum y_n} \quad (14)$$

Here, $\bar{y}_n$ signifies normalized firing strengths.

Defuzzification layer: Then, in the defuzzification layer ($K_{4,n}$), each node possesses a node function, and it is determined as,

$$K_{4,n} = \bar{y}_n \cdot (\Omega, \Theta) = y_n (\varepsilon_n \mu_\phi + k_n) \quad (15)$$

Where, ε_n and k_n signify the parameter set.

Output layer: The final output is discovered by estimating the whole addition of all the arriving signals from the previous node. The output layer ($K_{5,n}$) is formulated as,

$$K_{5,n} = \sum_n \bar{y}_n \cdot (\Omega, \Theta) = \frac{\sum_n y_n (\varepsilon_n \mu_\phi + k_n)}{\sum_n y_n} \quad (16)$$

Ultimately, the predicted stress level of engineering students (S) is given as,

$$S = \langle H, M, L \rangle \quad (17)$$

Here, H indicates high stress, M depicts medium stress, and L shows low stress.

3.8 Stress Management Suggestions

If the stress level is high (H) and medium (M), then coping strategies-based stress management suggestions are provided to the students. Coping strategies are a set of suggestions that are used to tolerate and reduce stress events.

3.9 Engineering Students' Academic Performance Prediction System

Similarly, engineering students' academic performance prediction system is trained as follows,

3.9.1 Dataset

Primarily, to train the prediction model, the student academic performance dataset is taken, and it is defined as $\mathcal{G}_m^{data}$.

3.9.2 Data Cleaning

Then, based on numeralization and normalization, $\mathcal{G}_m^{data}$ is pre-processed. Here, the cleaned data is indicated as Φ_e .

3.9.3 Feature Extraction

Next, from Φ_e , the features, such as StudentAbsenceDays, GradeID, SectionID, and Discussion are extracted and are represented as $\tilde{\lambda}_z$.

3.9.4 Prediction

Next, by using A²RQNFIS, the engineering students' academic performance is predicted based on $\tilde{\lambda}_z$. In Section 3.7, the steps involved in A²RQNFIS are explained. The predicted academic performance (P) is written as,

$$P = \langle \hat{h}, \varpi, \ell \rangle \quad (18)$$

Where, $\hat{h}$, ϖ , and ℓ show the high, medium, and low performances, respectively.

3.10 Correlation Analysis

Then, the correlation analysis is done between the predicted stress level variables (S_g) and academic performance variables (P_i) based on the (S) and (P) by using PCC.

$$Cor = \frac{\sum (S_i - \bar{S})(P_i - \bar{P})}{\sqrt{\sum (S_i - \bar{S})^2 \sum (P_i - \bar{P})^2}} \quad (19)$$

Here, Cor denotes the correlation value, $\bar{S}_1$ depicts the mean of S_1 , and $\bar{P}_1$ implies the mean of P_1 . Likewise, Cor is identified for all (S_g) and (P_i).

3.11 Impact Analysis on Academic Performance

Lastly, based on Cor , impact analysis (I_A) is performed.

$$I_A = \begin{cases} \text{if } Cor = \text{high} & \text{high-impact} \\ \text{if } Cor = \text{low} & \text{less-impact} \end{cases} \quad (20)$$

Therefore, the proposed model proficiently predicted the stress level of engineering students and analyzed its impacts.

4. RESULT AND DISCUSSION

Here, the proposed model's performance assessment is done to prove its trustworthiness. The proposed model is implemented in the working platform of PYTHON.

4.1 Dataset Description

To assess the proposed model, the student's stress factor dataset and student academic performance dataset are used. In the reference section, the dataset link is mentioned. Here, the student's stress factor dataset consists of 1100 students' stress factor information. Similarly, the student academic performance dataset contains 480 number of students' academic performance information. From that, 80% of data are employed for training and 20% of data are utilized for testing.

4.2 Performance Validation

Here, the performance validation of the proposed model and prevailing techniques is done.

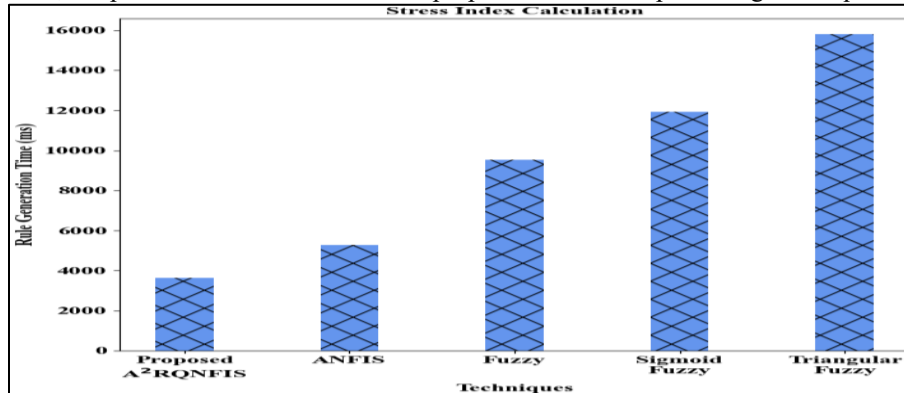


Figure 3: Rule generation time analysis

The rule generation time analysis of the proposed model is displayed in Figure 3. For rule generation time, the proposed A²RQNFIS obtained a low value of 3624ms, whereas the existing techniques like ANFIS, Fuzzy, Sigmoid Fuzzy, and Triangular Fuzzy attained high values.

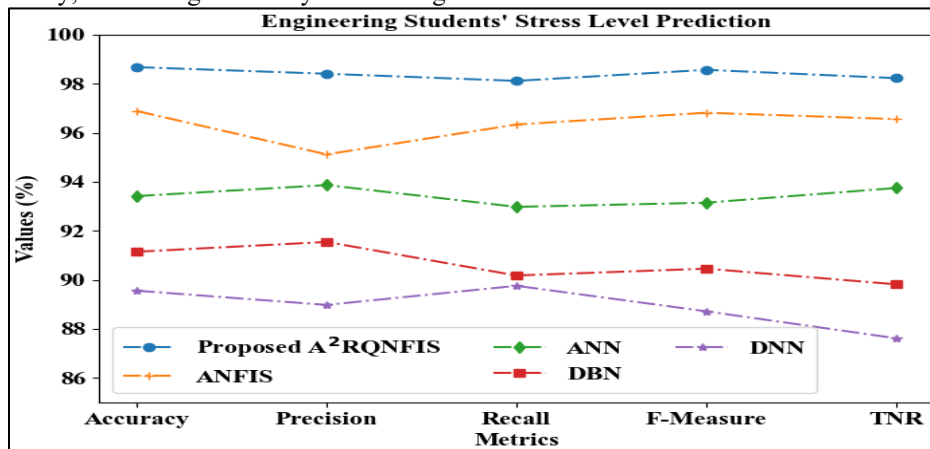


Figure 4: Performance estimation based on performance metrics

In Figure 4, the performance estimation based on performance metrics is shown. For accuracy, precision, recall, F-measure, and True Negative Rate (TNR), the proposed A²RQNFIS achieved high percentages of 98.68%, 98.41%, 98.12%, 98.57%, and 98.23%, respectively, while the prevailing techniques like ANFIS, Artificial Neural Network (ANN), Deep Belief Network (DBN), and Deep Neural Network (DNN) attained low-performance metrics.

Table 1: Comparative assessment

Techniques	Training time (ms)
Proposed A ² RQNFIS	35724
ANFIS	45914
ANN	75149
DBN	95743
DNN	113912

Table 1 shows the comparative evaluation of the proposed A²RQNFIS with the conventional methods. For training, the A²RQNFIS took a less time of 35724ms, whereas the prevailing methods took a high time of 82679.5ms.

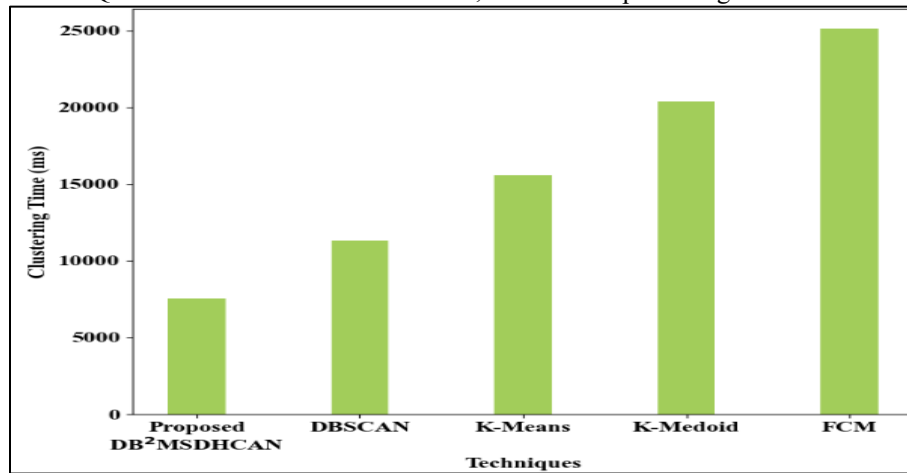


Figure 5: Clustering time validation

Figure 5 analogizes the proposed model with the existing techniques regarding clustering time. The DB²MSDHCAN attained a low clustering time of 7562ms. But, the existing methods attained a high clustering time of 18095.25ms.

Table 2: Performance estimation

Techniques	Silhouette score
Proposed DB ² MSDHCAN	0.982
DBSCAN	0.965
K-Means	0.937
K-Medoid	0.908
FCM	0.883

Table 2 shows the performance estimation regarding silhouette score. Here, the proposed DB²MSDHCAN achieved a high silhouette score of 0.982, whereas the prevailing methods, such as DBSCAN, K-Means, K-Medoid, and Fuzzy C-Means (FCM) attained low silhouette scores.

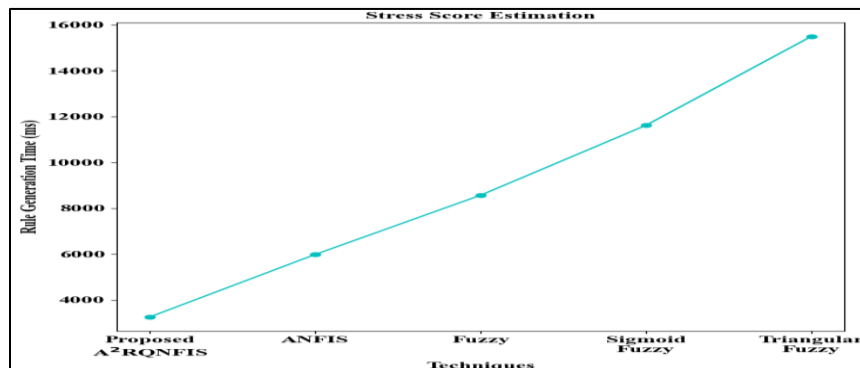


Figure 6: Graphical analysis of rule generation time

The graphical analysis of rule generation time is displayed in Figure 6. For stress score estimation, the proposed A²RQNFIS obtained a low rule generation time of 3256ms; yet, the prevailing methods attained high rule generation times.

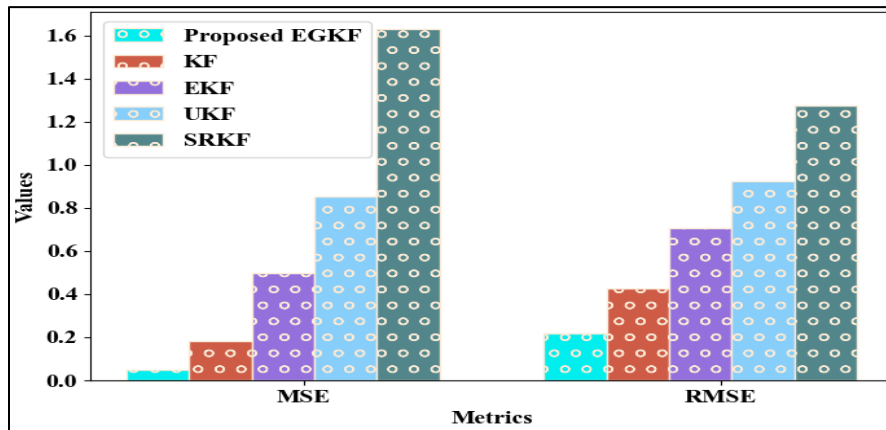
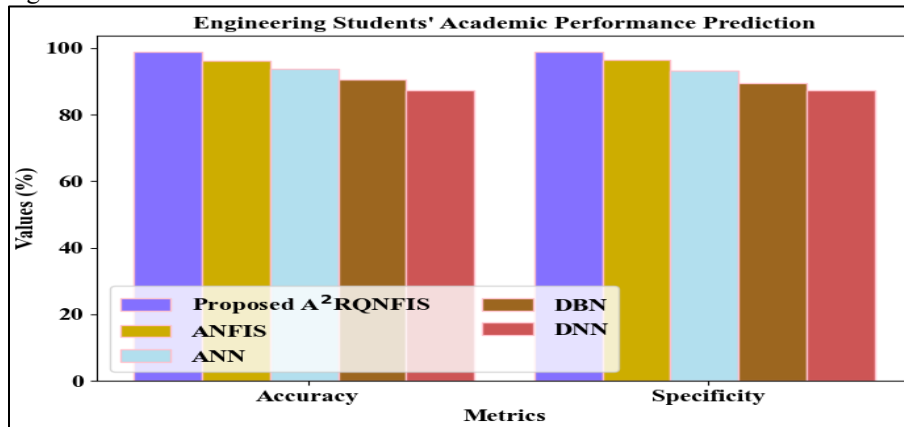
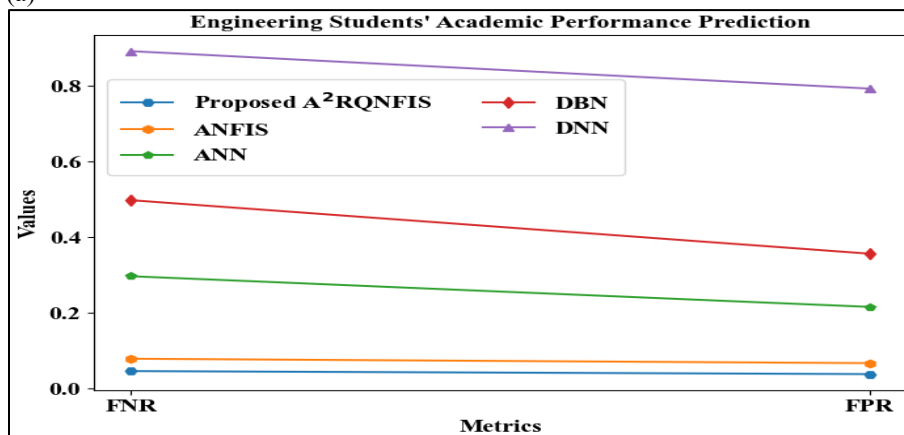


Figure 7: Comparative assessment of the proposed model

In Figure 7, the proposed model is weighed against the prevailing techniques. The proposed EGKF achieved a low Mean Squared Error (MSE) and Root Mean Square Error (RMSE) of 0.0467 and 0.2161, whereas the conventional KF, Extended Kalman Filter (EKF), Unscented Kalman Filter (UKF), and Square Root Kalman Filter (SRKF) attained high error values.



(a)



(b)

Figure 8: Graphical representation regarding (a) Accuracy, Specificity (b) FNR, FPR

The graphical representation of the proposed A²RQNFIS and prevailing methods is depicted in Figure 8. For accuracy and specificity, the proposed A²RQNFIS obtained a high percentage of 98.78% and 98.77%, respectively. Similarly, with the help of the Arctangent Rational Quadratic membership function, the proposed A²RQNFIS attained a low False Negative Rate (FNR) and False Positive Rate (FPR). But, poor performance metrics were attained by the prevailing methods like ANFIS, ANN, DBN, and DNN.

4.3 Comparative Analysis

Here, the comparative analysis of the proposed model and related works is performed.

Table 3: Comparative analysis

Authors' name	Techniques	Accuracy (%)	Precision (%)	F-measure (%)
Proposed model	A ² RQNFIS	98.68	98.41	98.57
(Walambe et al., 2021)	ANN	96.67	95	95
(R. V. Anand et al., 2023)	Ensemble learning	93.48	-	93.14
(Du, 2022)	XGBoost	77.5	-	-
(Chen & Lee, 2023)	Self-supervised CNN	93.42	-	88.11
(Anand et al., 2024)	CNN	87.63	-	-

The proposed model is weighed against the related works in Table 3. For accuracy, precision, and F-measure, the proposed model achieved a high percentage of 98.68%, 98.41%, and 98.57%, respectively. Similarly, the existing ANN, Ensemble learning, eXtreme Gradient Boosting (XGBoost), self-supervised CNN, and CNN obtained poor performance in predicting the stress level of engineering students.

5. CONCLUSION

Here, vital signs-based engineering students' stress level prediction and impact analysis on academic performance using A²RQNFIS are presented. To assess the proposed model, the Student Stress Factor dataset was employed. For stress level prediction, a high accuracy of 98.68% was attained by the proposed A²RQNFIS. Similarly, a low clustering time of 7562ms was attained by the proposed DB²MSDHCAN. Overall, the proposed framework had superior efficiency and low time complexity. However, the model only predicted the present stress level of students. Moreover, it failed to focus on the long-term impact analysis of stress in students. This highlighted a significant problem in understanding the long-term consequences of chronic stress on young individuals' lives. Also, the proposed model didn't provide deeper insights into how sustained stress influenced cognitive abilities, learning processes, decision-making, and professional growth over time.

Future Scope

Improved techniques will be developed in the future to analyze how chronic stress affects academic performance and long-term career outcomes. These improved approaches will likely integrate innovative tools like longitudinal studies, advanced statistical modeling, and AI to offer deeper insights into chronic stress.

We have no conflicts of interest to disclose. All authors declare that they have no conflicts of interest.

REFERENCES

1. Anand, T., Alam, M. S., Akila, D., Yadav, M. J., Mavliya, A. K., & Saran Kumar, A. (2024). Towards Mental stress Detection in University Students Based on RBF and Extreme Learning Based Approach. 1st International Conference on Electronics, Computing, Communication and Control Technology, ICECCC 2024, 1–6. <https://doi.org/10.1109/ICECCC61767.2024.10593904>
2. Anand, R. V., Md, A. Q., Urooj, S., Mohan, S., Alawad, M. A., & C, A. (2023). Enhancing Diagnostic Decision-Making: Ensemble Learning Techniques for Reliable Stress Level Classification. *Diagnostics*, 13(22), 1–25. <https://doi.org/10.3390/diagnostics13223455>
3. Balamurugan, M., Mayasre, S. G., & Kirthika, H. (2023). An Intelligent Tool to Predict and Analyze Students' Stress for Their Academic Growth. 2023 Intelligent Computing and Control for Engineering and Business Systems, ICCEBS 2023, 1–4. <https://doi.org/10.1109/ICCEBS58601.2023.10448969>
4. Bork, S. J., & Mondisa, J. L. (2022). Engineering graduate students' mental health: A scoping literature review. *Journal of Engineering Education*, 111(3), 665–702. <https://doi.org/10.1002/jee.20465>

5. Chen, Q., & Lee, B. G. (2023). Deep Learning Models for Stress Analysis in University Students: A Sudoku-Based Study. *Sensors*, 23(13), 1–22. <https://doi.org/10.3390/s23136099>
6. Deng, Y., Cherian, J., Khan, N. U. N., Kumari, K., Sial, M. S., Comite, U., Gavurova, B., & Popp, J. (2022). Family and Academic Stress and Their Impact on Students' Depression Level and Academic Performance. *Frontiers in Psychiatry*, 13, 1–13. <https://doi.org/10.3389/fpsyt.2022.869337>
7. Du, W. (2022). Application of Improved SMOTE and XGBoost Algorithm in the Analysis of Psychological Stress Test for College Students. *Journal of Electrical and Computer Engineering*, 1–8. <https://doi.org/10.1155/2022/2760986>
8. Durán Acevedo, C. M., Carrillo Gómez, J. K., & Albarracín Rojas, C. A. (2021). Academic stress detection on university students during COVID-19 outbreak by using an electronic nose and the galvanic skin response. *Biomedical Signal Processing and Control*, 68, 1–10. <https://doi.org/10.1016/j.bspc.2021.102756>
9. Feng, G., Fan, M., & Chen, Y. (2022). Analysis and Prediction of Students' Academic Performance Based on Educational Data Mining. *IEEE Access*, 10, 19558–19571. <https://doi.org/10.1109/ACCESS.2022.3151652>
10. Geronimo, S. M., Hernandez, A. A., & Abisado, M. B. (2023). Academic Stress of Students in Higher Education using Machine Learning: A Systematic Literature Review. *ICSET 2023 - 2023 IEEE 13th International Conference on System Engineering and Technology, Proceeding*, 141–146. <https://doi.org/10.1109/ICSET59111.2023.10295141>
11. Jensen, K. J., & Cross, K. J. (2021). Engineering stress culture: Relationships among mental health, engineering identity, and sense of inclusion. *Journal of Engineering Education*, 110(2), 371–392. <https://doi.org/10.1002/jee.20391>
12. Jiao, P., Ouyang, F., Zhang, Q., & Alavi, A. H. (2022). Artificial intelligence-enabled prediction model of student academic performance in online engineering education. *Artificial Intelligence Review*, 55(8), 6321–6344. <https://doi.org/10.1007/s10462-022-10155-y>
13. Liu, S., Zhang, Y., Zhao, L., & Liu, Z. (2024). Academic stress detection based on multisource data: a systematic review from 2012 to 2024. *Interactive Learning Environments*, 1–27. <https://doi.org/10.1080/10494820.2024.2387744>
14. Morales-Rodríguez, F. M., Martínez-Ramón, J. P., Méndez, I., & Ruiz-Esteban, C. (2021). Stress, Coping, and Resilience Before and After COVID-19: A Predictive Model Based on Artificial Intelligence in the University Environment. *Frontiers in Psychology*, 12, 1–15. <https://doi.org/10.3389/fpsyg.2021.647964>
15. Nijhawan, T., Attigeri, G., & Ananthakrishna, T. (2022). Stress detection using natural language processing and machine learning over social interactions. *Journal of Big Data*, 9(1), 1–24. <https://doi.org/10.1186/s40537-022-00575-6>
16. Parthiban, K., Pandey, D., & Pandey, B. K. (2021). Impact of SARS-CoV-2 in Online Education, Predicting and Contrasting Mental Stress of Young Students: A Machine Learning Approach. *Augmented Human Research*, 6(1), 1–7. <https://doi.org/10.1007/s41133-021-00048-0>
17. Sergio, W. L., Ströele, V., Dantas, M., Braga, R., & Macedo, D. D. (2024). Enhancing well-being in modern education: A comprehensive eHealth proposal for managing stress and anxiety based on machine learning. *Internet of Things (Netherlands)*, 25, 1–24. <https://doi.org/10.1016/j.iot.2023.101055>
18. Siddique, A., Jan, A., Majeed, F., Qahmash, A. I., Quadri, N. N., & Wahab, M. O. A. (2021). Predicting academic performance using an efficient model based on fusion of classifiers. *Applied Sciences (Switzerland)*, 11(24), 1–19. <https://doi.org/10.3390/app112411845>
19. Siddique, S., Baidya, S., & Rahman, M. S. (2021). Machine Learning based model for predicting Stress Level in Online Education Due to Coronavirus Pandemic: A Case Study of Bangladeshi Students. *2021 5th International Conference on Electrical Information and Communication Technology, EICT 2021*, 1–7. <https://doi.org/10.1109/EICT54103.2021.9733612>
20. Walambe, R., Nayak, P., Bhardwaj, A., & Kotecha, K. (2021). Employing Multimodal Machine Learning for Stress Detection. *Journal of Healthcare Engineering*, 2021, 0–1. <https://doi.org/10.1155/2021/9356452>