Fuzzy Logic Enabled Stress Detection Using Physiological Signals

Shabbar Naqvi[1(✉)], Aamir Zeb Shaikh[2], Talat Altaf[3], and Saurabh Singh[4]

[1] Department of Computer Systems Engineering, Balochistan University of Engineering and Technology, Khuzdar, Pakistan
shabbar@buetk.edu.pk
[2] Department of Electronic Engineering, NED University of Engineering and Technology Karachi, Karachi, Pakistan
[3] Department of Electrical Engineering, Sir Syed University of Engineering and Technology, Karachi, Pakistan
[4] Department of Industrial and Systems Engineering, Dongguk University Seoul, Seoul, South Korea

Abstract. Stress is attributed as the natural response of body towards unwanted and challenging conditions of society and environment. The consequences of stress are in general very harmful. However, in some specific situations, stress can be highly serious to the human health as it impacts the cardiovascular system in addition to other body sub systems. Timely Detection of stress through physiological sensors may help in arresting the disease. As the stress results in change of heart rate, skin conduction, temperature, blood pressure and oxygen levels, hence, measurement and assessment of these parameters is useful in deciding the stress levels into a candidate. In this paper, a fuzzy logic based automatic stress detection system is designed to timely detect the patients passing through this silent killer disease. The physiological signals of human body are used to assess the current state of person. The parameters used for the purpose are heart rate, Galvanic Skin Response (GSR), and temperature. The fuzzy logic is an exciting branch of artificial intelligence that is used to make useful decisions under uncertain and incomplete input knowledge. A synthetic data set of 500 patients is also developed to train and test the proposed architecture. The algorithms used for this purpose are Hill Climbing (HC) and Simulated Annealing (SA) for fuzzy membership functions training. The results show that Simulated Annealing gives a testing accuracy of 89% in comparison to Hill climbing with 81% accuracy. Future work is directed towards using new methods like type-2 fuzzy logic and deep learning etc.

Keywords: Stress detection · Fuzzy logic · Physiological signals

1 Introduction

Stress is one of the largest prevalent harmful silent killer diseases in the world. Sometimes, the consequences of stress can be fatal if it is not diagnosed and treated timely and

M. H. Miraz et al. (Eds.): iCETiC 2021, LNICST 395, pp. 161–173, 2021.
https://doi.org/10.1007/978-3-030-90016-8_11

efficiently. There are many diseases caused by hyper stress. It increases the chances of cardiovascular disease that may increase the mortality rate [1]. This is in addition to the COVID-19 patients trying for suicide [2]. However, these precious lives can be saved if the disease is treated timely. Cannon's research study shows that when a person passes through a threatening like situation, his or her body responds in the form of flight- fly fashion [3]. Hence, his or her body produces higher respiratory rate and activates bigger blood flow that requires more oxygen level [4, 5]. Additionally Dr. Rosalind Picard of Massachusetts Institute of Technology published an exciting book in the field of Affective Computing. This book introduces the connection of physiological changes of human body with emotional state [6]. Hence, the changes in human body directly affects the mental state of a person.

Stress has become an integral part of the modern life and society. There are many events in which one cannot escape from its detrimental effects. These include truck drivers travelling for long hours on highways, social pressure due to employment and unemployment, candidates passing through tough recruitment assessments and interviews, students preparing for examinations, patients suffering from COVID-19 disease and flight-phobia patients travelling on commercial flights [7].

However, it is an important fact that stress results in various variations in human body. These variations can be assessed through diagnostic tests. Hence, timely evaluation and diagnosis of disease may recommend in taking useful decisions regarding treatment of patient. This will also save the precious human lives. Some of the testing procedures include Trier Social Test, Stroop color-word inference test, Montreal imaging stress task, cold pressor test, sing a song stress test [7].

Furthermore, human vital signs can be evaluated through physiological sensors that can be attached on a human body in non-invasive fashion. These sensors can sense the required parameters periodically and compare those with pre-set threshold regarding presence or absence of risky stress levels. Once, the values rise above the threshold, the information can be transmitted to the subject as well as medical consultant who would provide suitable consultation to manage the given situation and avoid any fatal mishap.

The vital signs used by various researchers for making suitable decisions include heart rate, breathing rate, temperature, humidity, speech, blood pressure, galvanic skin response, photoplethysmogram, electrocardiogram, electromyogram. The researchers formulate the binary problem of presence or absence of stress for a patient. Different artificial intelligence based algorithms are used by authors to make intelligent decisions in diversified fields, these include fuzzy logic, genetic algorithm, and neural networks, support vector machine (SVM), Naïve Bayes, and Decision Tree etc. [8–12].

Fuzzy logic is an exciting area of Artificial Intelligence that uses incomplete or imprecise information to come up with better decisions. This paper uses parameters i.e. Galvanic skin response (GSR), heart rate and temperature to predict the mental state of a person. The parameters are fed to a Fuzzy Inferencing System. The motive behind selection of the parameters is that the literature shows that two parameters are sufficient to identify the mental state of a candidate most of the time [13]. These include GSR and heart rate. However, the third parameter will give additional reliability in decision making process in which fuzzy inferencing system with imprecise data might be useful. The results are fused using fuzzy logic algorithm. Additionally, 500 synthetic data set

elements are also used to train and test the system. Two algorithms are used for training and testing purpose. These include Hill Climbing (HC) and Simulated Annealing (SA) algorithms which have been used to train the fuzzy membership function parameters for finding optimal values. The results show that SA performs better than HC Algorithm.

The rest of the paper is organized as follows. Section 2 presents the related work done by other researchers to detect the presence or absence of risky stress levels. Section 3 presents the proposed setup whereas Sect. 4 provides results with its discussion. Section 5 is the last section which concludes the paper and also provides future direction.

2 Related Work

Several researchers have demonstrated the significance of the automated systems for identification of risky and normal stress levels [14–17]. These researchers collect the physiological information from subjects and formulate the problem of classification whether the person is going through abnormal stress levels or not. The decisions are computed through several algorithms. This section presents a brief review of the work done by the researchers.

In [18], authors use electrocardiogram(ECG), GSR and respiratory rate (RESP) signals to detect the presence of Stress into a human being. As the previous observations based on recent research describe that the physiological signals contain pivotal information about the mental state of a person. Hence, the extracted data is processed to extract useful information. The processing includes detection of R peaks or when decomposing the GSR signal. Additionally RESP signal is used to identify the stress level of the people. Hence, the improvement results in better performance in comparison to other systems. This research work uses image processing techniques to provide useful decisions regarding the presence of disease.

In [13], researchers use heart rate and GSR levels of a candidate to detect the stress levels. Additionally, they claim that these two parameters are sufficient to segregate between normal and stressed patients. The database is also developed to test the proposed system. The database contains 80 females in the age bracket from 19 to 32 years. The database acquisition is based on physiological experiments carried out by doctors. The key benefit offered by the proposed setup is that it is a non-invasive system. The authors use fuzzy logic to decide the presence or absence of disease. The proposed scheme is computationally efficient and highly accurate. The proposed setup gives an accuracy of 99.5% using 10 s to extract the stress template and 7 s to detect stress on an individual using two physiological signals and GSR measured only during two tasks.

In [19], authors use respiratory rate, heart rate variability, oxygen saturation and temperature to formulate a stress level detection system. The proposed system is designed using fuzzy logic architecture. The wearable sensors are used to collect vital signs of the human being which are exploited in the next phase to detect the disease in candidates. The performance of the proposed setup shows good results.

In [14], researchers measure heart rate, GSR and breathing rate to design an intelligent system for discrimination of relaxed state and stressed state of a human being. The proposed system uses fuzzy logic model to decide the state of a person. The benefits of the developed system includes computational efficiency under low budget requirements.

The proposed system is implemented using an Arduino and Raspberry Pi Boards. The data collection is completed through Arduino while data processing task is performed through Raspberry Pi board. Identification of stress is achieved on F1 score of 91.5% and relaxation at 96.81%. The processing time is 20 s sliding window. The proposed system is also validated on 42 persons.

In [20], researchers formulate the stress detection system for long-time computer users. It is observed that the long usage of screen time typically induces stress into a user. The physiological data collected for the purpose is heart rate and GSR. The final decision is devised using fuzzy logic. The proposed system is implemented for the faculty and students of Computer science department at U C San Carlos. The proposed system gives an accuracy of 72%.

In [21], authors model a fuzzy logic based stress detection system for travelers. Two inputs are considered, these include speed and traffic density. The inputs are used to model six driving postures i.e. idle, journey, high urban workload, low urban workload, high non-urban workload and low non-urban workload. The proposed system is validated using real –world data collected from eight participants.

In [22], authors have used fuzzy inferencing to model the stress faced by students during COVID-19 in University education. Three types of factors including controllable, intermediate and uncontrollable have been defined. Mamdani type inferencing with Triangular membership functions has been used. Results have been divided into three categories called reflecting short term, medium term and long-term stress management schemes for university students with a focus on far flung Universities of Pakistan. It has been concluded that fuzzy system can model students stress in an efficient manner.

The literature review shows that identifying stress using automated intelligent systems is an important area of research and there is need to investigate various soft computing methods. In this research, a fuzzy logic-based system with membership functions training through HC and SA algorithms for stress recognition using physiological sensors has been developed.

In the next section, the proposed system is elaborated along with the required results and discussion.

3 Proposed Fuzzy Based Stress Detection System

This section presents the proposed setup for identification of stress through physiological sensors. The signals of interest for the proposed system are assumed as heart rate, GSR and temperature. These parameters are fed to a fuzzy Mamdani system. Each of the inputs is distributed in three levels i.e. low, medium and high. The results are decided into the binary classification issue i.e. stressed or normal. The stress identification factors are now elaborated.

Heart Rate

Heart Rate measures the breathing rate of a person. Studies show that this parameter is significantly related to the detection of stress levels in a human body [23]. Heart rate displays the heart activity when Autonomous Nervous System (ANS) reacts to cope up with increasing demands of the human body. Hence, it is dependent on the stimuli

which initially provoked the body. The value of heart rate above 50 shows the candidate is healthy. If the value comes out to be 14–25, it is attributed as slightly stressed and 2–15 with hyper stressed.

Galvanic Skin Response

Skin temperature is also one of the key parameters to detect the mental health of a person. It is also known as Electro Dermal Activity (EDA). It measures the skin conductance [24, 25]. Typically, GSR electrodes are connected to a human being to measure the sweat levels of a person. Hence, GSR indicates the healthy human being by showing lower GSR levels and higher levels for person being stressed.

Temperature

The literature shows that the body temperature is also a pivotal parameter to detect the mental state of person in connection with other parameters. The average body temperature of an individual is around 36–37 °C. Hence, a change in human being can be arrested as the temperature changes from the listed levels.

The FIS consists of three input variables Heart Rate, GSR and Temperature. Each of these variables has three membership functions low, medium, and high. The output of the system is Normal or Stressed based on two membership function values. Mamdani type Inferencing has been used and based on the type of parameter, triangular or Trapezoidal membership functions have been used. Centroid defuzzification method has been used. Figure 1 shows the proposed setup for identification of stressed person through physiological sensors. Different Physiological sensors as available in the literature might be used for obtaining reliable data. After computing machine has determined the diagnosis using fuzzy system, the result is sent to patients and consultants. This can help consultants to understand the case better and also taking patients into confidence for future plan regarding treatment if stress is confirmed by the system.

Fig. 1. Shows the proposed setup.

Figures 2, 3 and 4 show the input levels of sensors fed to the System. The output levels of the proposed system are shown in Fig. 5.

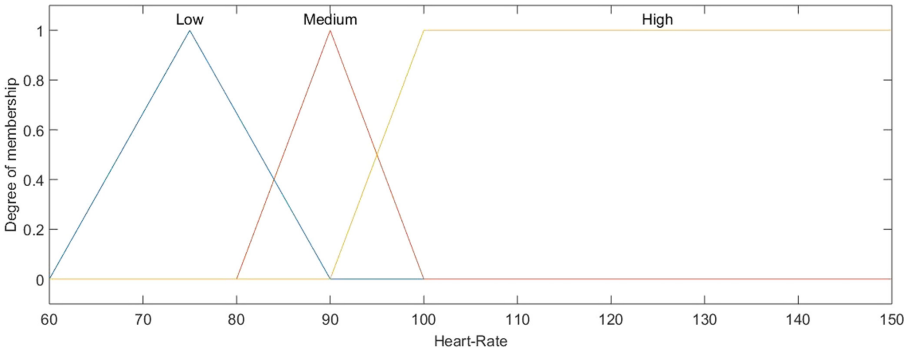

Fig. 2. Shows the heart rate levels for FIS system

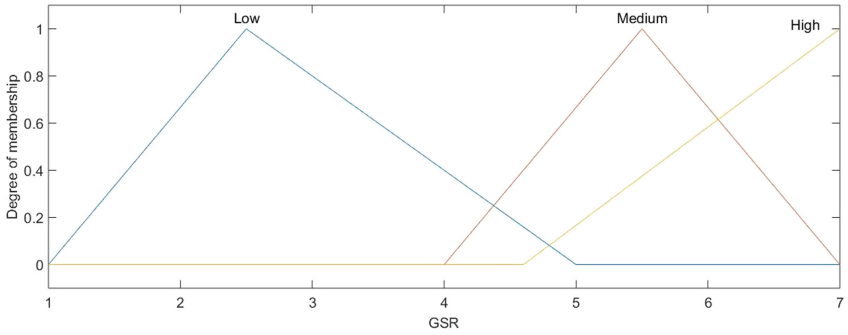

Fig. 3. Shows the GSR levels

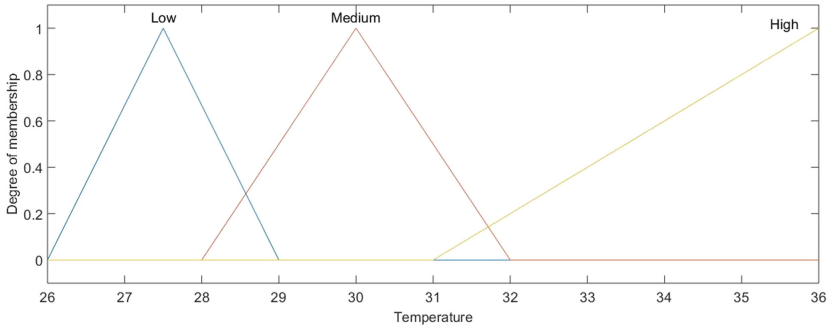

Fig. 4. Shows the temperature levels

The proposed system is implemented through following procedural steps to reach out to the Stressed or Normal Conditions of a person. These steps are elaborated in Fig. 6. It can be seen that once fuzzy inferencing system (FIS) has been evaluated with HC and SA algorithms, accuracy acceptability is determined. It is acceptable only when the current result is better than the previous result, otherwise the system goes back to the previous position in both cases of HC and SA [26].

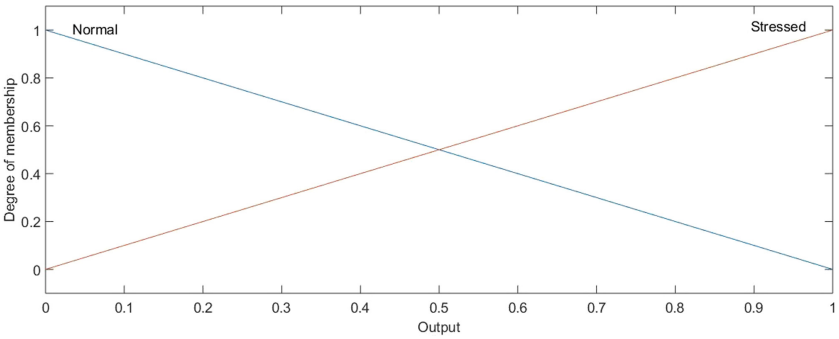

Fig. 5. Shows output levels

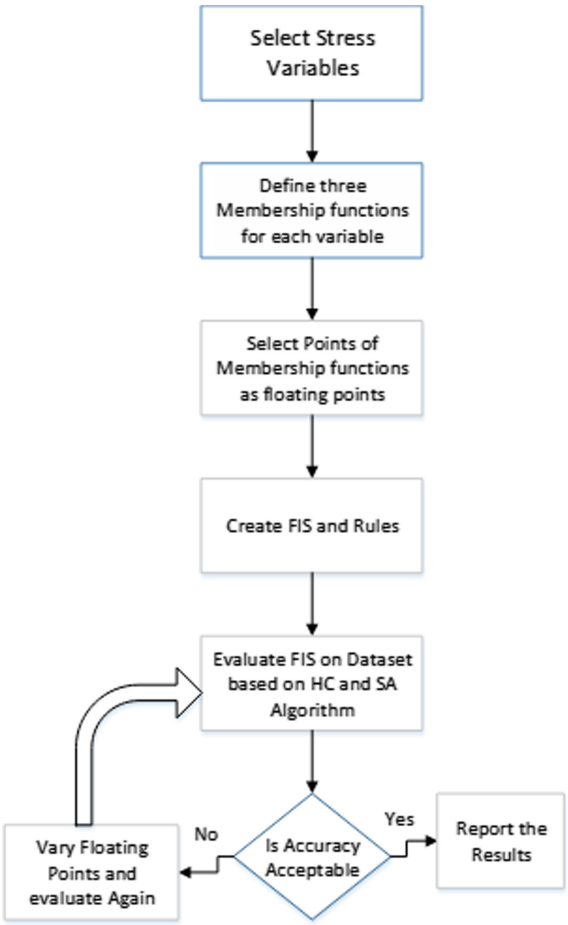

Fig. 6. Shows the implementation steps of the proposed algorithmic calculation of stress levels.

Figure 7 Shows the proposed FIS setup with inputs and output. The rules for the setup are shown in Fig. 8.

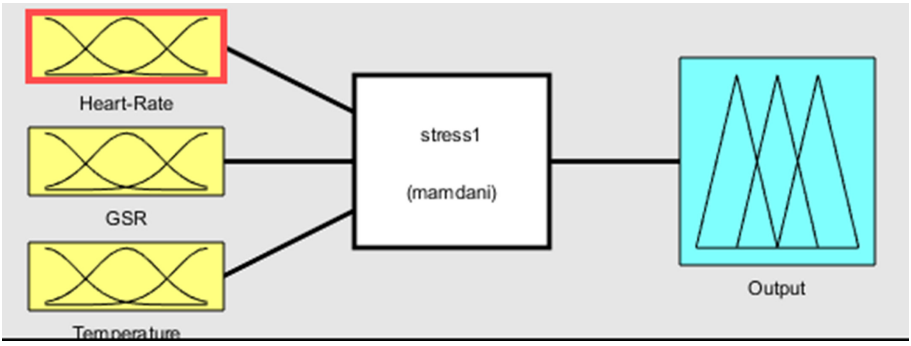

Fig. 7. Shows the proposed fuzzy design

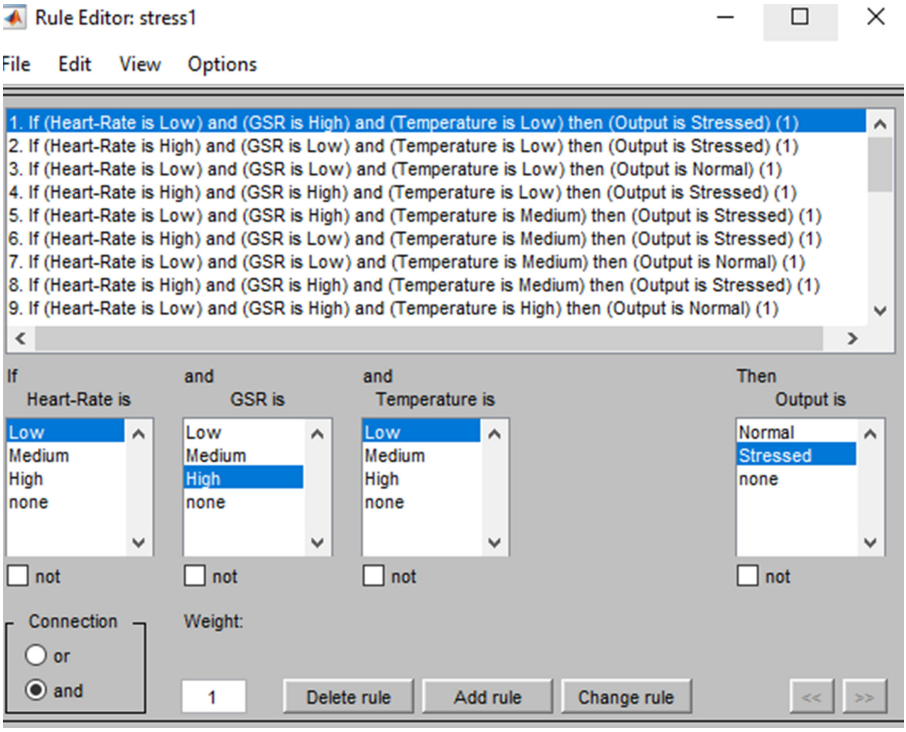

Fig. 8. Input and output relations in proposed setup

Once the basic system has been created, HC Algorithm has been used to train the membership functions. For this purpose, Floating Points have been used which are corners of the membership functions for each variable. These floating points have been

given random values in incremental and decremented manner to find the optimal value of the membership function suitable to the system. Each time an increment or decrement is made, system is evaluated and accuracy is compared and if found better then it is further incremented or decremented in the direction the accuracy is improving in the Hill Climbing fashion followed by SA algorithm. The system stops after 1000 iterations or if value does not improve for the 10 consecutive iterations which might indicate a local optimal solution. Figure 9 shows the optimum connections for proposed setup.

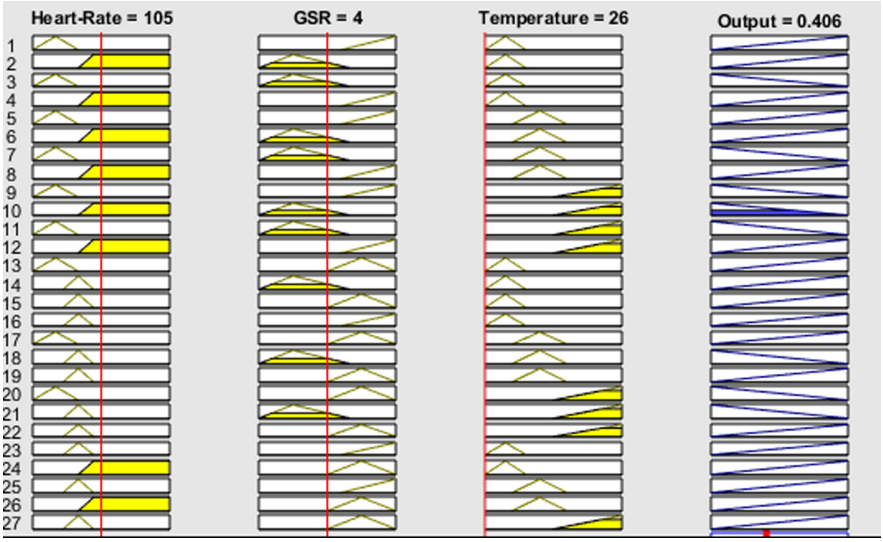

Fig. 9. Input output connections with rules

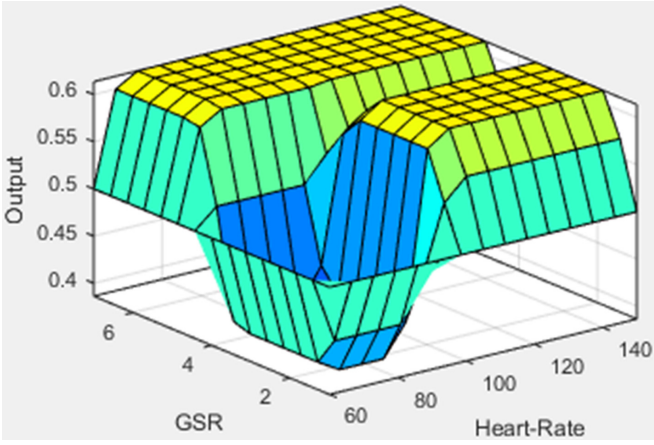

Fig. 10. Surface view of the proposed system with GSR and heart rate

Figure 10 shows the surface view of the output for the proposed setup. Clearly indicating the fact that under the condition that both of these inputs rise the probability of person being stressed is increase. Similarly, the similar outcome can be seen for the other input connections and the output. However, the results are similar as expected (Fig. 11).

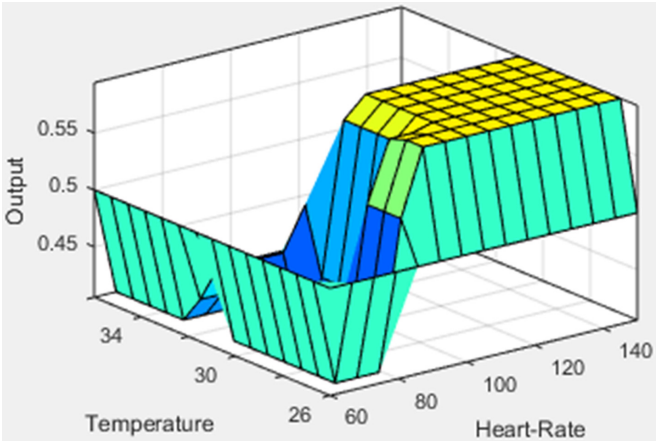

Fig. 11. Surface view of the proposed system with temperature and heart rate

4 Results and Discussion

The data set contains 500 synthetic entries towards various connections. The dataset has been divided into training and testing data. 60% data points were used for training and remaining 40% for testing. HC and SA algorithms are used to determine the optimal peak for the rational result. The best training Inferencing system was saved. The result of the best training is shown in terms of percentage accuracy is shown in Table 1:

Table 1. Training result in terms of percentage accuracy

Type	Percentage correct diagnosis	Percentage incorrect diagnosis
Training (HC)	81%	19%
Training (SA)	92%	8%

It can be seen from the Table that best training was provided by SA algorithm. It can also be seen that HC algorithm although did not perform well in comparison to SA algorithm but still results were still acceptable. The reason might be ability of SA algorithm to consider the bad solutions leading to good solutions on the basis of probability [26]. The results of the testing data have been shown in Table 2:

Table 2. Testing result in terms of percentage accuracy

Type	Percentage correct diagnosis	Percentage incorrect diagnosis
Testing (HC)	80%	20%
Testing (SA)	89%	11%

It can be seen from Table 2 that testing data results are also in line with the training data. SA algorithm was able to provide higher accuracy in terms of stress diagnosis. HC algorithm had higher percentage of incorrect diagnosis. These results also reaffirm the results of the literature that in certain cases, SA algorithm performs better as compared to HC when the results are likely to converged into local optimal solution [27]. However, to get more confidence in the results, different fitness functions, temperatures are required to be investigated.

5 Conclusion and Future Work

Stress is a silent killer. However, this disease can be detected through assessing a change in vital signs of a person. These vital signs can be detected through physiological sensors. In this paper, a Fuzzy Inferencing system is proposed and implemented that takes three input variables and decides the presence of presence or absence of risky stress levels in a human body. Mamdani inferencing scheme has been used with triangular membership functions. To find the optimal values of membership function parameters, HC and SA algorithms have been used. Floating point membership parameters have been identified and trained. The final output of the proposed system classifies the case as normal or stressed. The results suggest that the proposed system can be highly useful in the modern age, there are many events in which stress is increased and we most of the people passing through this disease are unable to identify. The testing efficiently shows that the SA algorithm results in better performance in comparison to the HC algorithm. In future, more real time datasets would be obtained and compared with the existing system in addition to using type-2 fuzzy logic and deep learning to investigate the level of complexities in the datasets as type-2 fuzzy logic has shown to provide better results in case of high level of complexity. Different fitness functions and temperatures would also be investigated for SA algorithm. Besides that, noninvasive sensors shall be used to gather vital signs of persons stress and integrate them in the current system.

Acknowledgment. Dr. Shabbar Naqvi would like to thank the administration of Balochistan University of Engineering and Technology Khuzdar, Balochistan, Pakistan for providing resources to complete the research.

References

1. Cohen, B.E., Edmondson, D., Kronish, I.M.: State of the art review: depression, stress, anxiety, and cardiovascular disease. Am. J. Hypertens. **28**(11), 1295–1302 (2015). https://doi.org/10.1093/ajh/hpv047

2. Liu, Y., Cao, L., Li, X., Jia, Y., Xia, H.: Awareness of mental health problems in patients with coronavirus disease 19 (COVID-19): a lesson from an adult man attempting suicide. Asian J. Psychiatr. **51**, 102106 (2020). https://doi.org/10.1016/j.ajp.2020.102106
3. Coan, J.A., Allen, J.J.B.: Frontal EEG asymmetry as a moderator and mediator of emotion. Biol. Psychol. **67**(1), 7–50 (2004). https://doi.org/10.1016/j.biopsycho.2004.03.002
4. Poon, C.-S., Siniaia, M.S.: Plasticity of cardiorespiratory neural processing: classification and computational functions. Respir. Physiol. **122**(2–3), 83–109 (2000)
5. Sadati, S.M.S., Qureshi, F.U., Baker, D.: Energetic and economic performance analyses of photovoltaic, parabolic trough collector and wind energy systems for Multan, Pakistan. Renew. Sustain. Energy Rev. **47**, 844–855 (2015). https://doi.org/10.1016/j.rser.2015.03.084
6. Picard, R.W.: Affective Computing. MIT Press, Cambridge (2000)
7. Can, Y.S., Arnrich, B., Ersoy, C.: Stress detection in daily life scenarios using smart phones and wearable sensors: a survey. J. Biomed. Inform. **92**, 103139 (2019). https://doi.org/10.1016/j.jbi.2019.103139
8. Ghulam, M., Yannick, F., Abdelkader, G., Michel, F., Hocine, N.: Level of detail based AI adaptation for agents in video games. In: 5th International Conference on Agents and Artificial Intelligence (ICAART) (2013).https://doi.org/10.1007/978-3-642-29966-7
9. Mahdi, G., Gouaich, A.: Interval based integrated real-time coordination for multi-agent systems. In: Proceedings of the 3rd International Conference on Agents and Artificial Intelligence - Volume 1: ICAART, pp. 664–669, (2011) https://doi.org/10.5220/0003188406640669
10. Baloch, S.A., Shaikh, A.Z.: Fuzzy logic enabled spectrum access scheme for cognitive radio applications. In: International Conference on Innovations in Computer Science (2018)
11. Baloch, S.A., Shaikh, A.Z., Ahmed, A.: Survey on fuzzy logic enabled cognitive radio. In: International Conference for Emerging Technologies in Computing, pp. 190–196 (2018)
12. Ahmed, M., Naqvi, S., Ali, I., Uddin, S., Shaikh, A.Z.: A fuzzy inferencing system for highlighting the complexities involved in electronic surveys with emotions. Int. J. Comput. Sci. Netw. Secur. **19**(10), 6–14 (2019)
13. de Santos Sierra, A., Avila, C.S., Casanova, J.G., del Pozo, G.: A stress-detection system based on physiological signals and fuzzy logic. IEEE Trans. Ind. Electron. **58**(10), 4857–4865 (2011). https://doi.org/10.1109/TIE.2010.2103538
14. Zalabarria, U., Irigoyen, E., Martinez, R., Larrea, M., Salazar-Ramirez, A.: A low-cost, portable solution for stress and relaxation estimation based on a real-time fuzzy algorithm. IEEE Access **8**, 74118–74128 (2020). https://doi.org/10.1109/ACCESS.2020.2988348
15. Chen, J., Abbod, M., Shieh, J.-S.: Pain and stress detection using wearable sensors and devices—a review. Sensors, **21**(4) (2021). https://doi.org/10.3390/s21041030
16. Albertetti, F., Simalastar, A., Rizzotti-Kaddour, A.: Stress detection with deep learning approaches using physiological signals. In: Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, pp. 95–111 (2020)
17. Durán-Acevedo, C.M., Carrillo-Gómez, J.K., Albarracín-Rojas, C.A.: Electronic devices for stress detection in academic contexts during confinement because of the COVID-19 pandemic. Electronics, **10**(3) (2021). https://doi.org/10.3390/electronics10030301
18. Salazar-Ramirez, A., Irigoyen, E., Martinez, R., Zalabarria, U.: An enhanced fuzzy algorithm based on advanced signal processing for identification of stress. Neurocomputing **271**, 48–57 (2018). https://doi.org/10.1016/j.neucom.2016.08.153
19. Lakshmi, B., Boban, E., Sulphikar, N., Aparna, T.M., Dhanya, S., Anjaly, S.V.: Mental stress calculation using fuzzy logic algorithm. Int. J. Appl. Eng. Res. **15**(1), 35–43 (2020)
20. Ceniza, A., Cantara, A.: Stress sensor prototype: determining the stress level in using a computer through validated self-made Heart Rate (HR) and Galvanic Skin Response (GSR) sensors and fuzzy logic algorithm. Int. J. Eng. Res. Technol., **5**(3) (2016)

21. Dobbins, C., Fairclough, S.: Detecting and visualizing context and stress via a fuzzy rule-based system during commuter driving. IEEE Int. Conf. Pervasive Comput. Commun. Workshops (PerCom Workshops) **2019**, 499–504 (2019). https://doi.org/10.1109/PERCOMW.2019.8730600
22. Karim, S., et al.: A fuzzy inferencing system for stress management of university students in COVID-19 for Pakistan. In: 2nd International Conference on Computational Sciences and Technologies, 17–19 December 2020 (INCCST 2020), MUET Jamshoro, pp. 5–10 (2020)
23. de Santos Sierra, A., Ávila, C.S., del Pozo, G., Casanova, J.G.: Stress detection by means of stress physiological template. In: 2011 Third World Congress on Nature and Biologically Inspired Computing, pp. 131–136 (2011). https://doi.org/10.1109/NaBIC.2011.6089448
24. Shi, Y., Ruiz, N., Taib, R., Choi, E., Chen, F.: Galvanic Skin Response (GSR) as an index of cognitive load. In: CHI 2007 Extended Abstracts on Human Factors in Computing Systems, New York, NY, USA: Association for Computing Machinery, pp. 2651–2656 (2007)
25. Zhai, J., Barreto, A.: Stress detection in computer users based on digital signal processing of noninvasive physiological variables. Int. Conf. IEEE Eng. Med. Biol. Soc. **2006**, 1355–1358 (2006). https://doi.org/10.1109/IEMBS.2006.259421
26. Naqvi, S.: Modelling FTIR Spectral Data with Type-I and Type-II Fuzzy Sets for Breast Cancer Grading, Ph. D. Thesis, The University of Nottingham for the Degree of Doctor of Philosophy. The University of Nottingham (2014)
27. Suman, B., Kumar, P.: A survey of simulated annealing as a tool for single and multiobjective optimization. J. Oper. Res. Soc. **57**, 1143–1160 (2006)