CHARACTERIZATION AND CLASSIFICATION OF STRESS USING PPG SIGNAL GUIDED BY GSR

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Motive of the Work

❑ Some statistics :

- According to The American Institute of Stress, approximately 33% of individuals experience severe stress and 73 to 77% experience stress that effects their mental and physical well-being
- Stress is the number one health concern among high school students
- One in five college students has thought about suicide once in their life due to stress
- The lowest stress levels are recorded in adults older than 72

❑So how can we address this issue?

- Our project aims to develop machine learning based system to detect and classify different stress generating events using physiological signals like GSR and PPG

Introduction

Basics of Stress

1. Definition :

- Stress is a feeling we all experience when we are challenged or overwhelmed
- The American Psychological Association (APA), defined stress as: "**The psychophysiological response to internal or external stressors**."
- Hans Selye defined stress as: **"The effects of anything that threatens the homeostasis of the body."**

2. Types :

a) Acute Stress :

- Short-term and immediate response to a specific event or situation.
- Examples – Public Speaking, Exam Stress, Travel Delay, Sudden Life Events

b) Episodic Acute Stress :

- Experiencing repeated episodes of acute stress.
- Examples – Constantly rushing from one task to another, feeling overwhelmed by daily responsibilities

c) Chronic Stress :

- Long-term and persists over an extended period.
- Examples – Work Related Stress, Financial Stress, Relationship Stress

3. Effects :

- Stress can be understood from both psychological and physiological perspective.
- Psychological effects: anxiety, depression, difficulty concentrating, reduced well-being.
- Physiological effects: increased blood pressure, weakened immune system, hormonal imbalances.
- In short term, effects of stress could be advantageous however long term exposure can lead to negative effects on health such as –

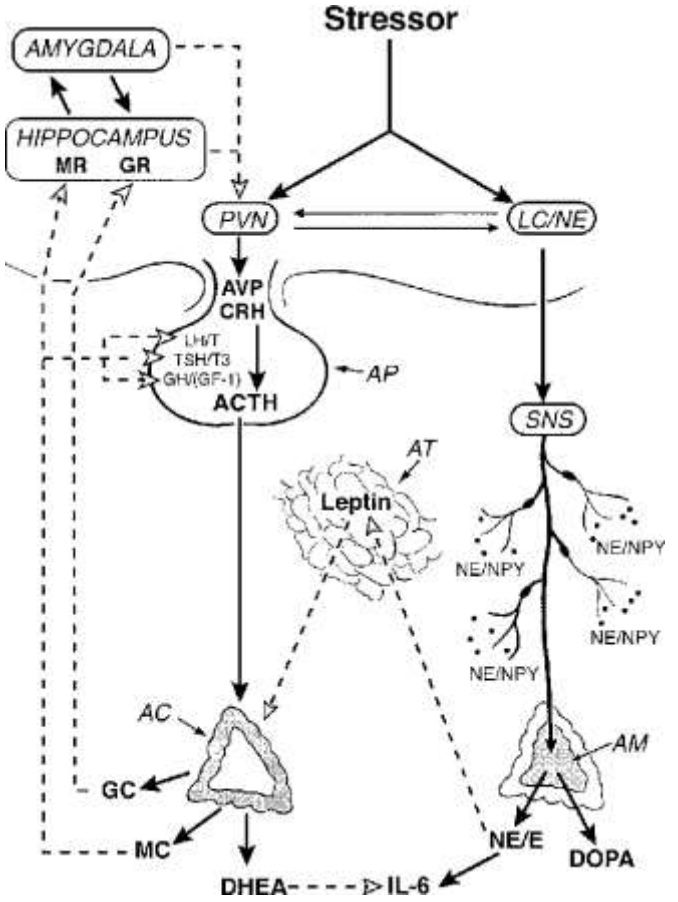
I. Cardiovascular disease
II. Diabetes
III. Obesity
IV. Ulcers
V. Asthma
VI. Allergies
VII. Headaches
VIII. Depression
IX. PTSD
X. Substance abuse

- Therefore, it is important to manage stress effectively and seek professional help if needed.

Stress and Bio-signals (GSR and PPG)

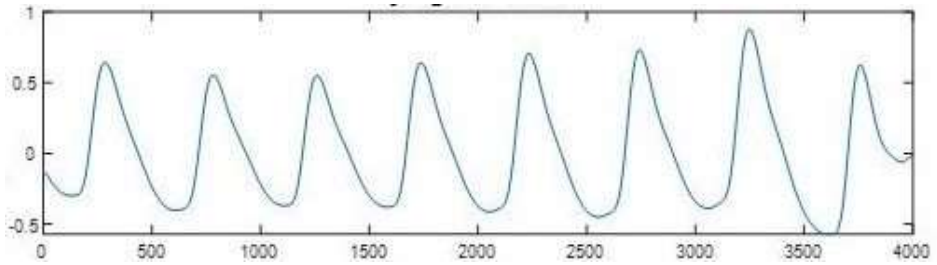
1. Physiological Origin :

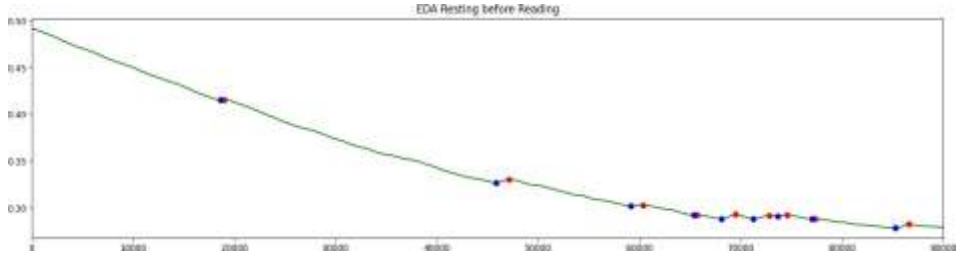
- Stress activates two main systems in the body: sympathetic nervous system and hypothalamic-pituitary-adrenal (HPA) axis.
- Sympathetic nervous system prepares the body for action by releasing norepinephrine and epinephrine, which increase arousal and mobilize energy resources.
- HPA axis responds to stressors by releasing CRH, ACTH, and cortisol, which regulate blood glucose levels, immune system activity, inflammation, memory and cognition.
- Short-term activation of these systems is adaptive, but chronic or dysregulated activation can have negative consequences on health and wellbeing.

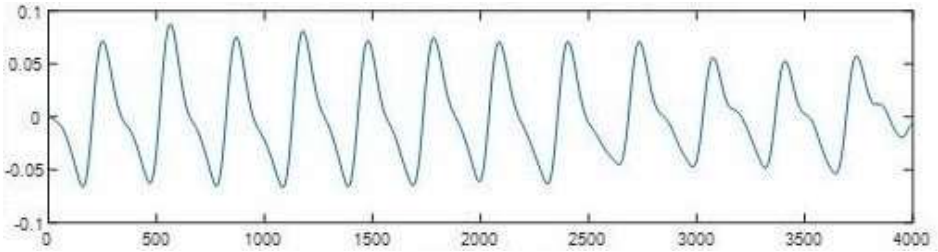


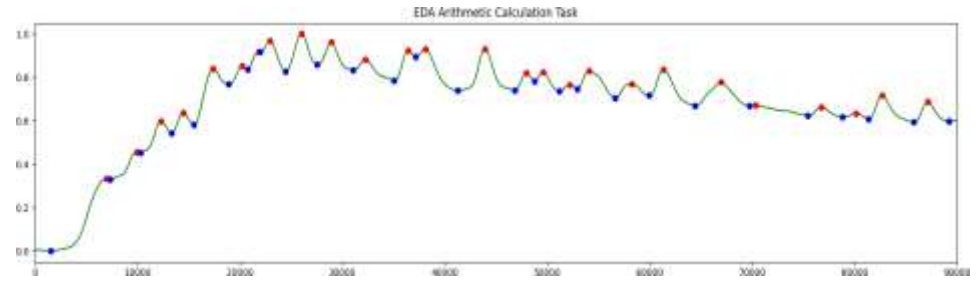
2. Significance of GSR and PPG signal in Stress Analysis

- In stress analysis, GSR and PPG provides crucial insights into the body's physiological response to stress.
- GSR provides objective measurement of stress levels and reflects emotional and physiological arousal during stress.
- PPG assesses cardiovascular responses and autonomic nervous system regulation during stress, offering insights into heart rate, blood pressure, and blood flow patterns.
- By leveraging GSR and PPG, researchers gain valuable insights into individual stress patterns, enabling personalized stress management and early identification of stress-related disorders.









Brief Introduction to GSR

❑GSR

- GSR(Galvanic Skin Response) is a measure of the continuous variations in the electrical characteristics (conductance) of the skin caused by the variation of the sweating activity of the human body.
- It is a indirect indicator of sympathetic nervous system.
- Various research has shown significant effect of stress in GSR Signal.

❑Information from GSR signal

- GSR can provide valuable insights into a range of phenomena including emotional responses , cognitive processing and physiological reactions to stress.
- It is particularly useful studies of anxiety fear and emotional states.

Brief Introduction to PPG

❑ PPG

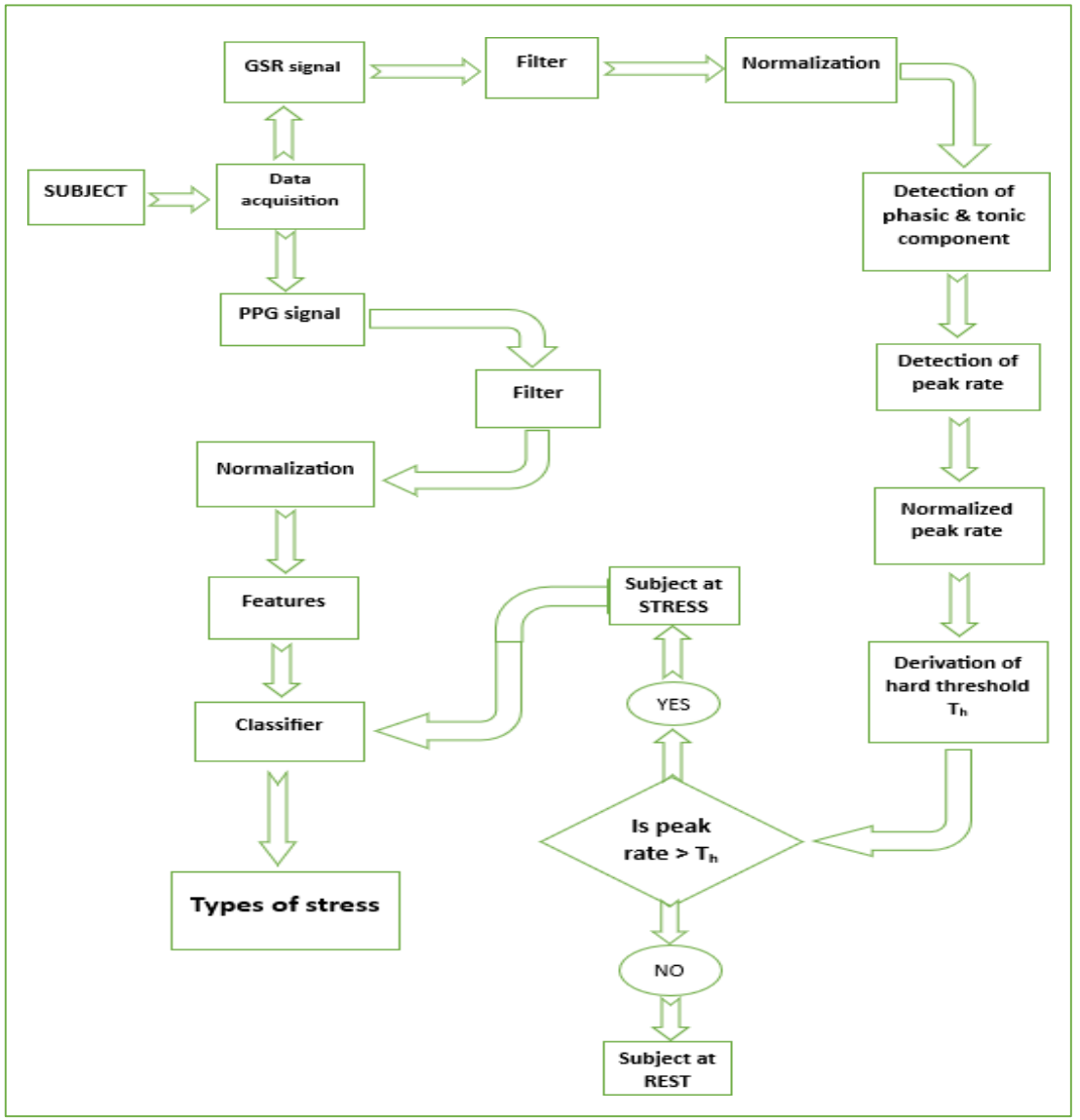
- Photoplethysmography (PPG) is an optical non-invasive method for measuring concurrent changes in blood volume in subcutaneous blood vessels during the cardiac cycle.
- Research has been prompted by the widespread use of PPG sensors in consumer wearables and various research also shown PPG can be used for stress analysis.

❑ Information from PPG signal

- The PPG signal contains valuable information on the cardiovascular, respiratory and autonomic nervous system, which can be useful in stress measurement.
- From the PPG signals the Heart rate (HR), Heart rate variability (HRV), blood oxygen saturation level (SpO2), and BP can be extracted.

Methodology

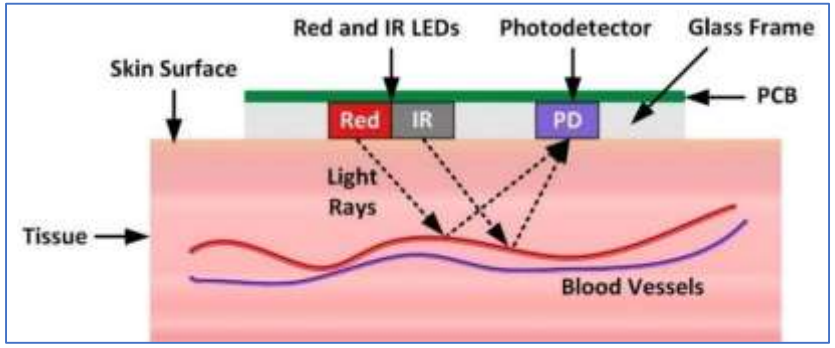
Flow Chart


GSR signal
Filter
Normalization
SUBJECT
Data acquisition
Detection of phasic & tonic component
PPG signal
Detection of peak rate
Filter
Normalization
Normalized peak rate
Features
Subject at STRESS
Derivation of hard threshold T_h
YES
Classifier
Is peak rate > T_h
Types of stress
NO
Subject at REST

Data Acquisition

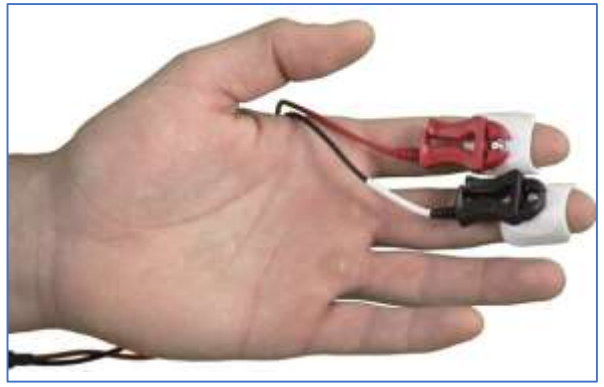
❑ **Working principle PPG Sensor:**

- PPG sensors use optical pulses generated by a red or near-infrared light source (light-emitting diode) and receive the reflected light (from the blood vessel) with a photodetector.



❑ **Working principle GSR Sensor:**

- GSR can be measured by passing a microcurrent of electricity through a pair of electrodes located near one another.



Data Acquisition

For data Acquisition we've used,

- **BIOPAC MP160**, a flexible, proven modular data acquisition & analysis system for life science research
- Pulse Bionomadix Transducer **BN-PULSE-XDCR** , the Wireless Photo Plethysmogram (PPG) and Electro dermal Activity (EDA/GSR) Bio-Nomadix module pair consists of a matched transmitter and receiver.

Data Acquisition

In order to cause mental stress and observe possible specific differences ,the participants were subjected to various external stimuli. The stimuli were:

1. **Reading:** The participants were asked to read a book for 3min.
2. **Music:** The participants were asked to listening to a music for 3min.
3. **Cognitive math:** The participants were asked to solve some verbal math problems.

Data is taken for 16min continuously and the time breakup of different tasks are as given in the table below,

No. of subject	Resting before Reading (min)	Reading (min)	Resting before Listening Music (min)	Listening Music (min)	Resting before Arithmetic Calculation Task(min)	Arithmetic Calculation Task (min)
12	3	3	2	3	2	3

Data Pre-Processing

This method can be obtained using filtering and normalization of PPG and GSR Signal.

- **Butterworth Filter:** It is a type of band-pass filter with a flat frequency response within a certain range and a rapid roll-off outside of that range. They are effective at removing high-frequency noise from a signal.

$$\left|H_b(jw)\right| = \frac{1}{\sqrt{1+\left(w/w_c\right)^{2N}}}$$

- **Moving Average Filter:** It is a type of low pass filter that takes the average of a group of consecutive samples in a signal, replacing each sample with that average. They can smooth out a signal and remove high-frequency noise, but may also introduce a delay and distort the shape of the underlying signal.

$$y[n] = \frac{1}{L}\sum_{k=0}^{L-1} x[n-k]$$

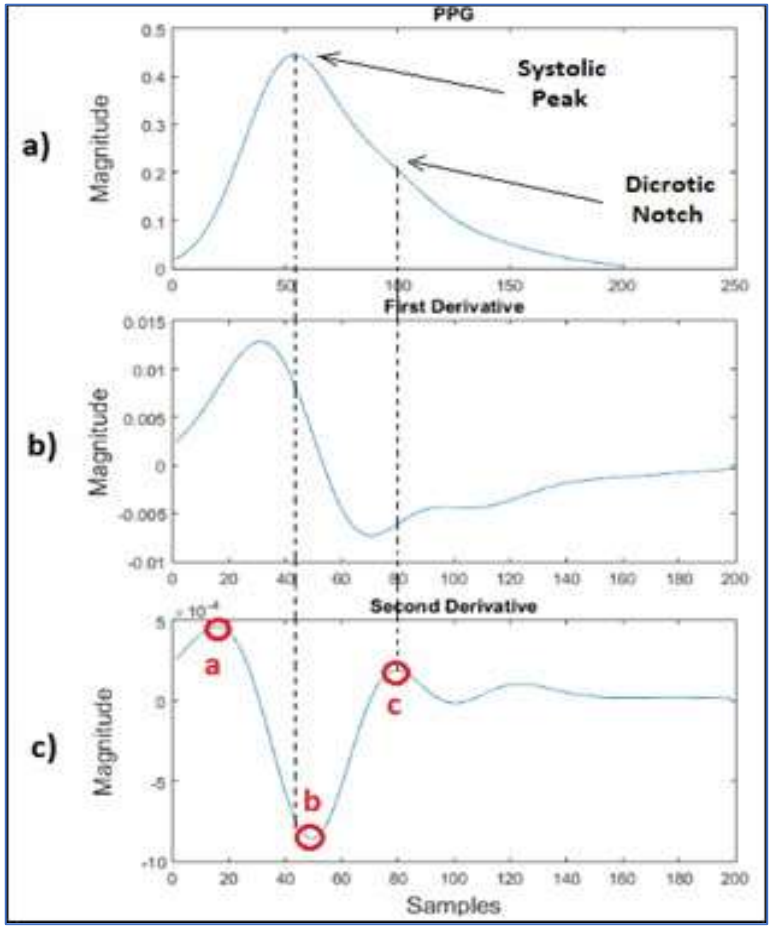
- **Normalization:** It is the last data pre-processing technique leads to all the signals irrespective of subject scaled in a predefined scale of range 0 to 1 that ensures to enhances comparability and improves accuracy.

$$Z = \frac{X_i - X_{min}}{X_{max} - X_{min}}$$

Feature Extraction

❑ Differentiation Stage:

- The 2nd derivative wave of the filtered PPG signal is used to extract a number of critical points.
- These critical points are the systolic peak, the minima of PPG signal, and the diacrotic notch which can be identified in 2nd order derivative as point B, point A and point C respectively.
- Once the systolic and diastolic peaks and dicrotic notch have been identified, the amplitude of the peaks and the time interval between the systolic peak and the next minima and Systolic peak rate within a certain time interval can be measured.

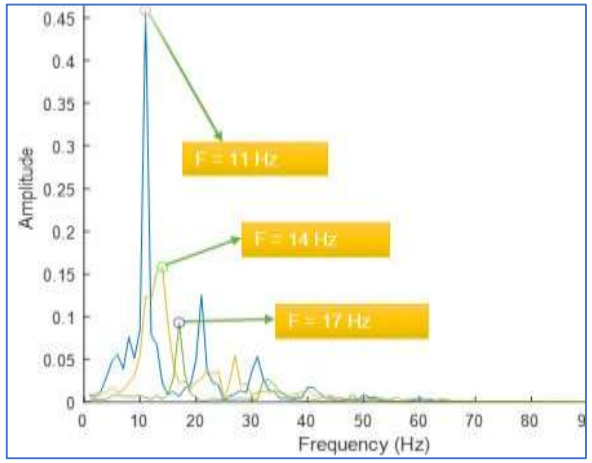


PPG signal and its 1st and 2nd order derivative

❑ Fast Fourier Transform:

- FFT is used to evaluate the dominant frequency of PPG Signal under different stressed condition. Mathematical equation is given below,

$$x[k] = \sum_{n=0}^{N-1} x[n] e^{\frac{-j2\pi kn}{N}}$$

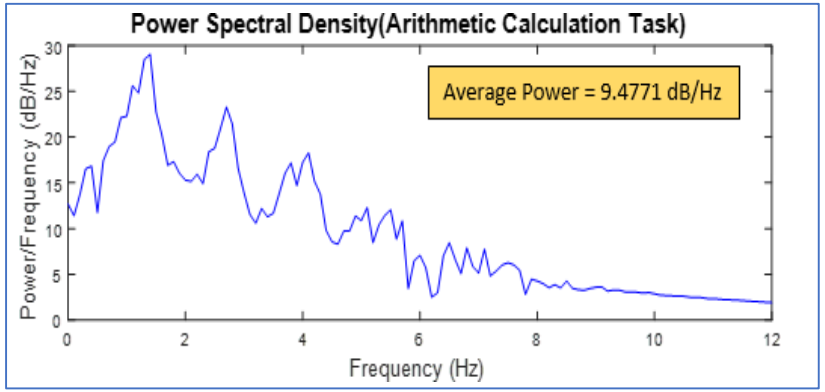


FFT Plot

❑ Power Spectral Density:

- PSD is a measure of the distribution of power over different frequencies in a signal.
- FFT can also be used to calculate power spectrum of the signal which can be further used to calculate the average power.
- The power spectral density (PSD) is then defined as the magnitude squared of the Fourier transform, so the formula for the PSD is

PSD = |X(f)|^2



PSD Plot

❑ Heart Rate:

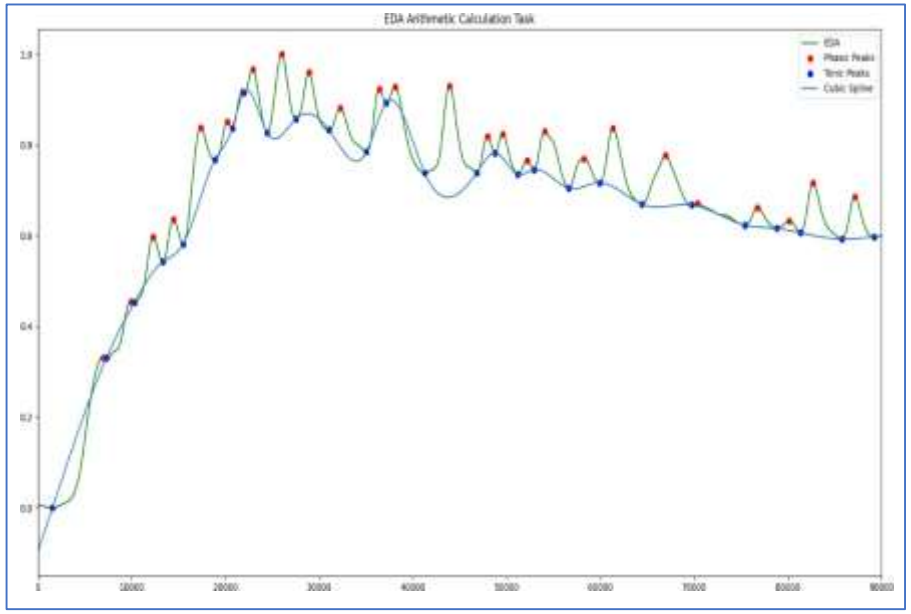
- The heart rate can be calculated from the time interval between consecutive systolic peaks in the filtered PPG signal.

$$\text{Heart Rate (H.R.)} = \frac{60F_s}{(t_2 - t_1)}$$

❑ Tonic and Phasic Components of GSR Signal :

- Phasic and Tonic components are two important aspects of the Galvanic Skin Response (GSR) signal as shown in figure.

- Both the components can be applied to extract number of peak occurred within a certain time interval, average, standard deviation and other features that is subjected to intensity of arousal activity and measure stress level.

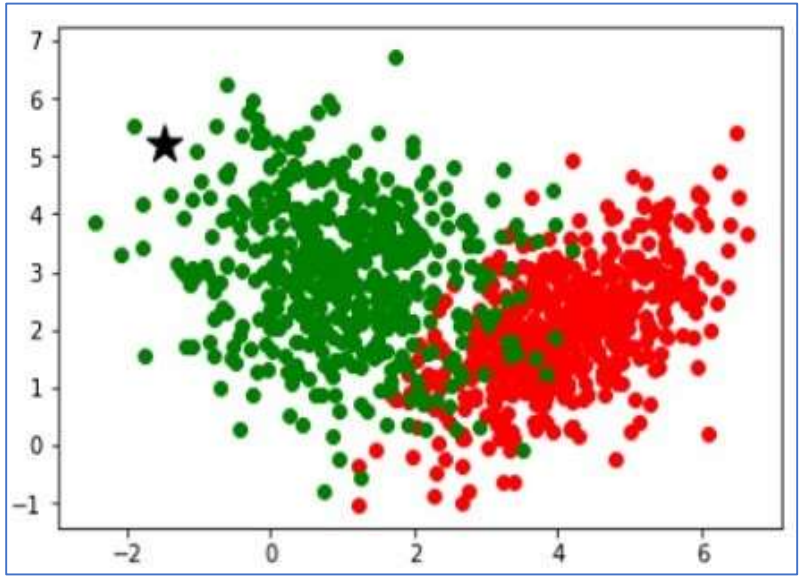


Detection of Phasic and Tonic Components in GSR Signal

Classification

❑ KNN:

- K-Nearest Neighbours (KNN) is a non-parametric method that classifies data based on its proximity to other points in the feature space.
- Weighted KNN is a modified version of k nearest neighbours that affect the performance of the KNN algorithm is the choice of the hyper parameter k.
- If k is too small, the algorithm would be more sensitive to outliers. If k is too large, then the neighbourhood may include too many points from other classes.
- This classifier divides datasets into a training set and a test set and then identify the classes over stress levels on the basis of features extracted.



A block of data separated as two classes

Result and Discussions

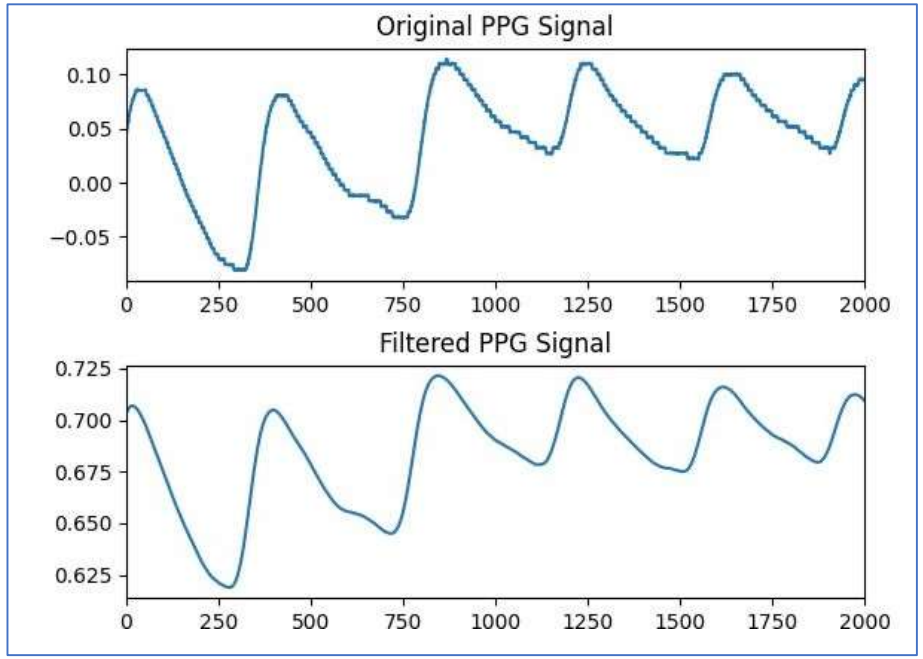
❑ De-noising GSR and PPG Signals:

- Two step filtering process is used to GSR and PPG signals in our study

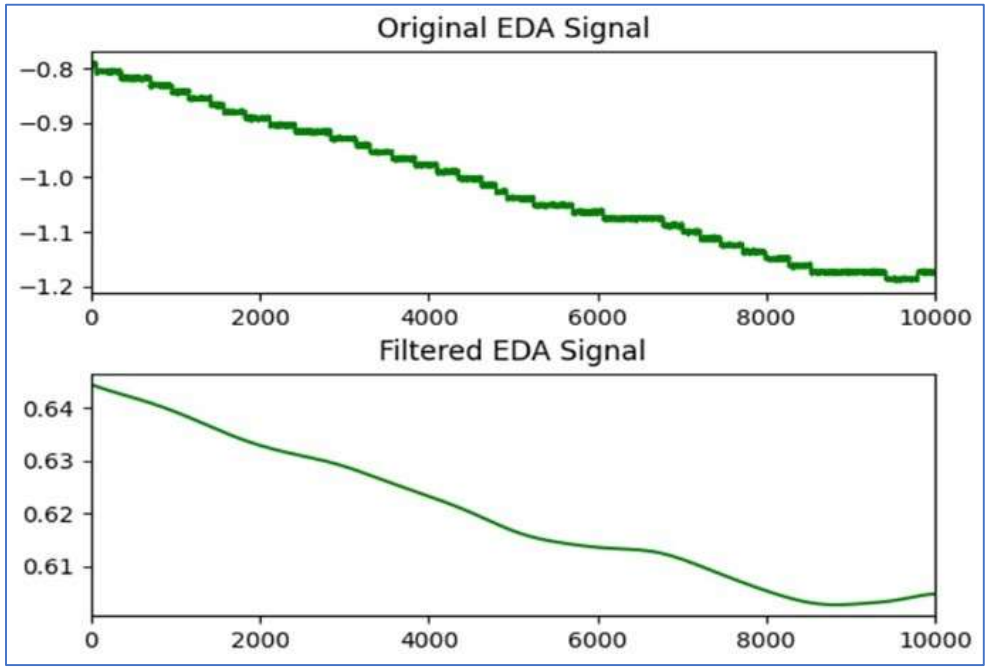
I. Filtering GSR and PPG Signals using Butterworth Filter

II. Filtering the Signals using Moving Average

III. Normalize both the signals



Original & Filtered PPG data



Original & filtered GSR Signal

❑ Detection of characteristic points of PPG Signals:

I. Amplitude difference of Systolic peak to previous minima(**h1**)

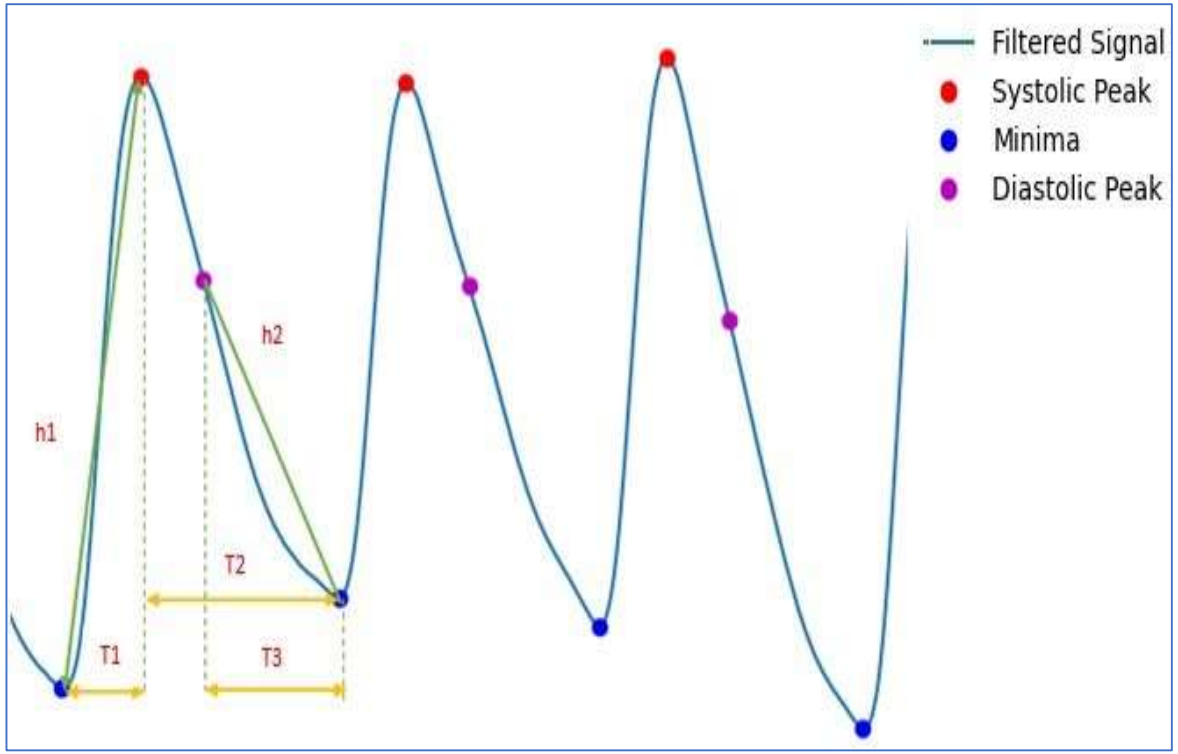
II. Time interval between previous minima to Systolic Peak(**T1**)

III. Time interval between Systolic Peak to next minima(**T2**)

Second derivative of de-noising signal is considered to extract the exact position of the Diastolic peak, where next minima of the minima is aligned with the Diastolic Peak of the PPG Signal.

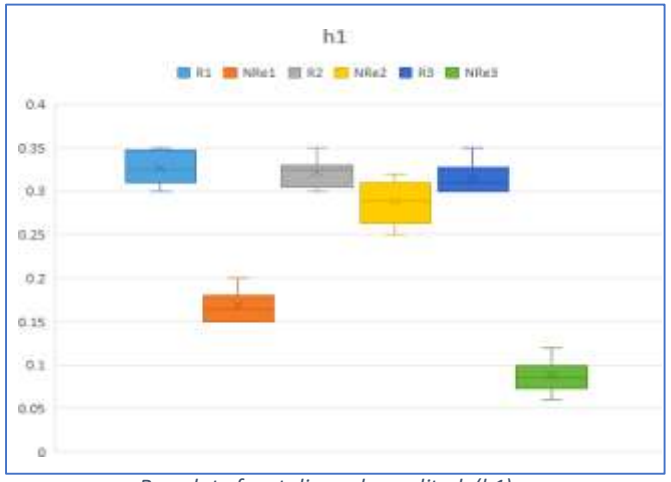
I. Amplitude difference of Diastolic peak to next minima(**h2**)

II. Time interval between Diastolic Peak to next minima(**T3**)

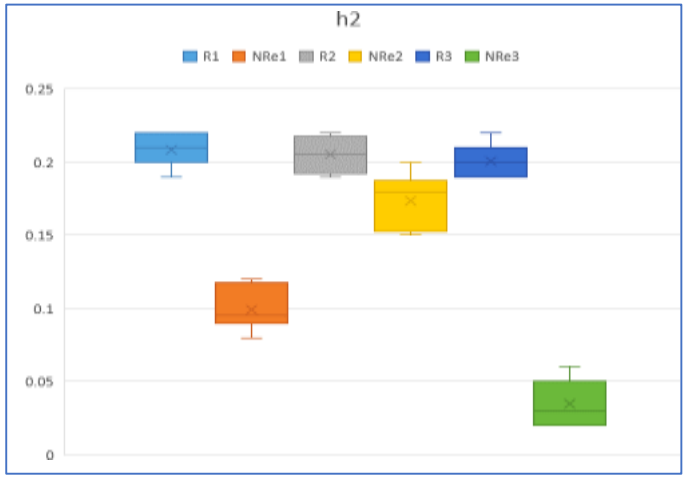


De-noising PPG Signal and its Second Order Derivative

❑ Distribution of values of characteristic points for various condition of one subject are mentioned in Boxplots:



Box plot of systolic peak amplitude(h1)



Box plot of diastolic peak amplitude (h2)

R1: Resting before Reading

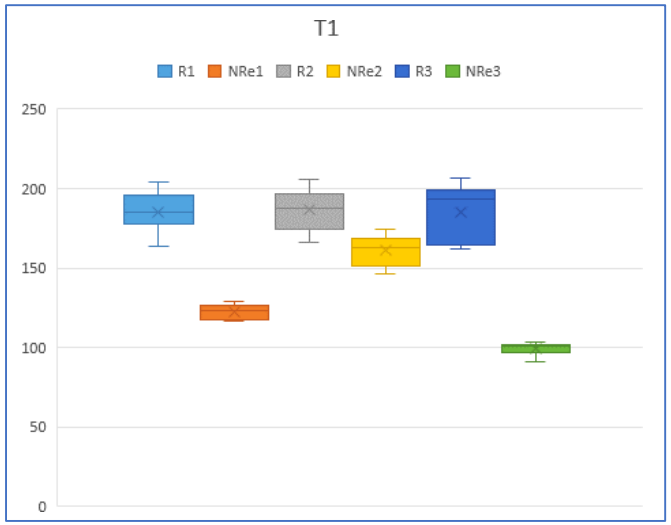
NRe1: Reading

R2: Resting before Listening Music

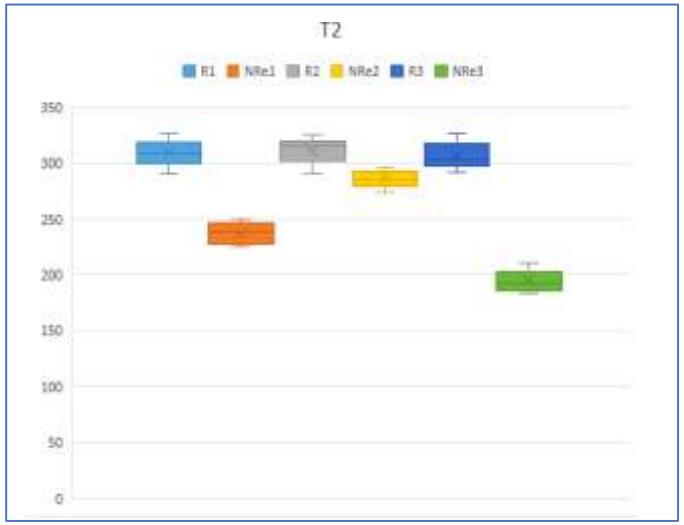
NRe2: Listening Music

R3: Resting before Arithmetic Calculation Task

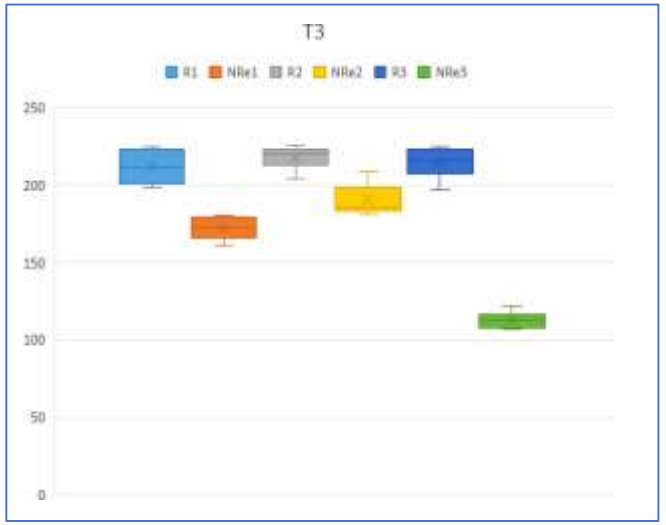
NRe3: Arithmetic Calculation Task



Box plot of T1



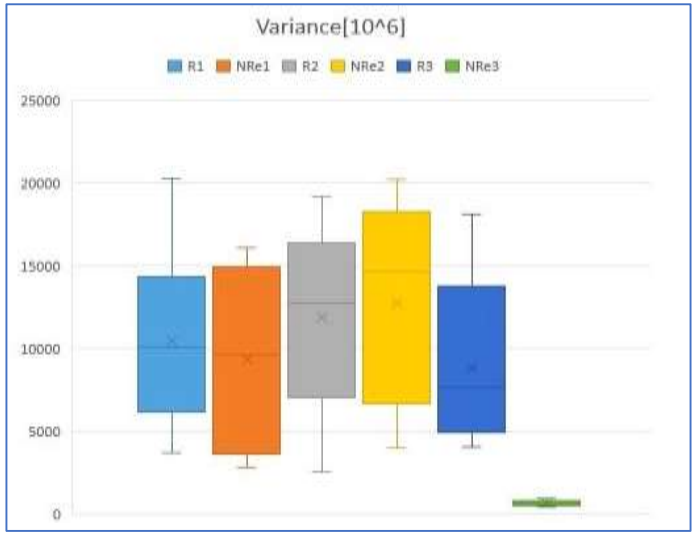
Box plot of T2

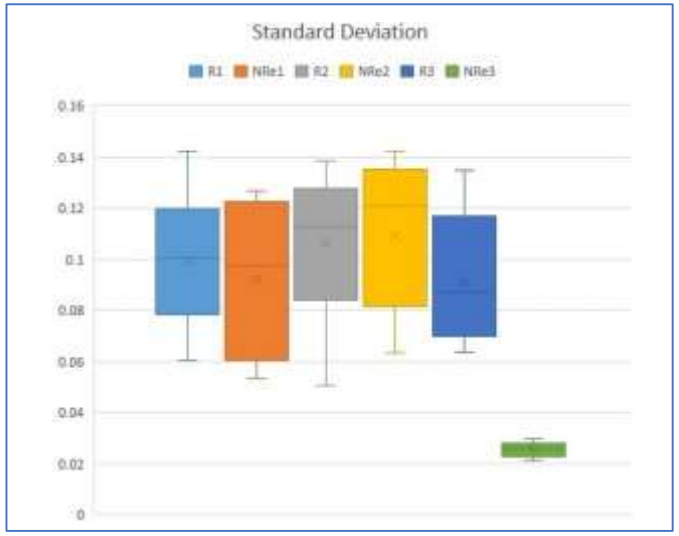


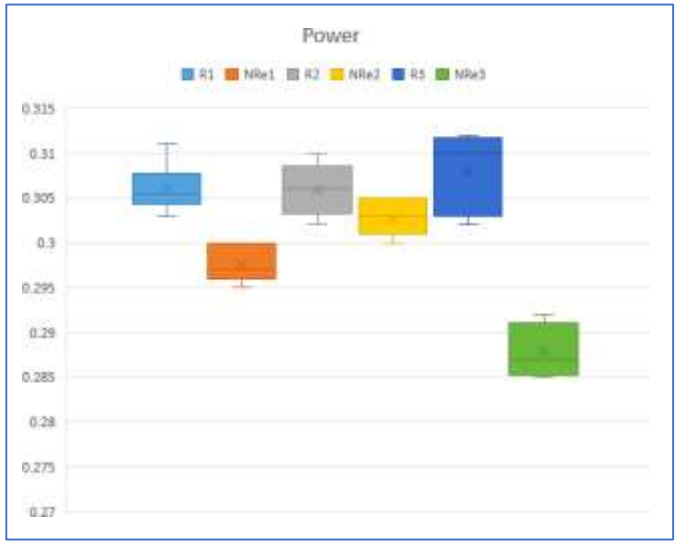
Box plot of T3

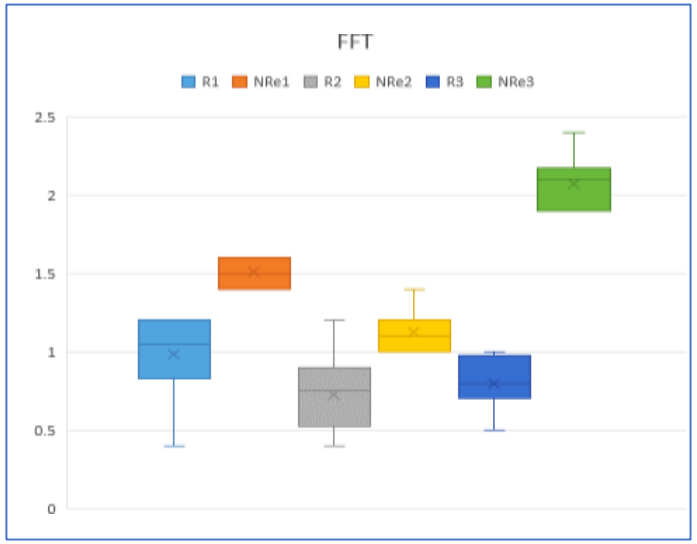
❑ Boxplot of PPG Features:

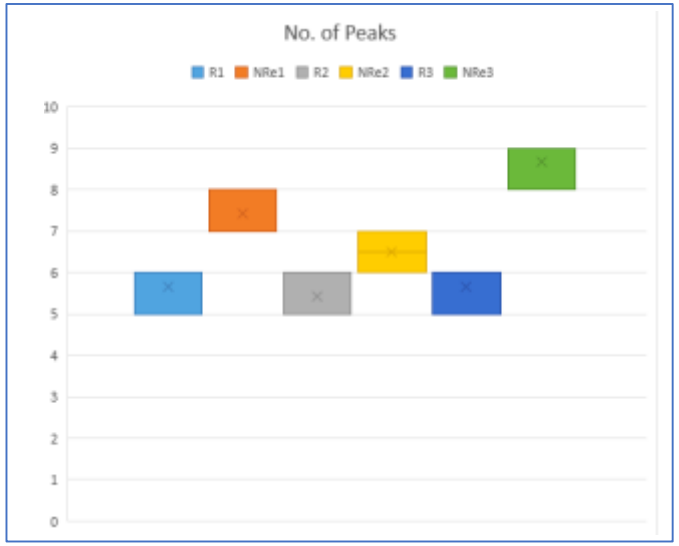
- Boxplot of extracted features from PPG signals shows significant changes with change in stressed condition:

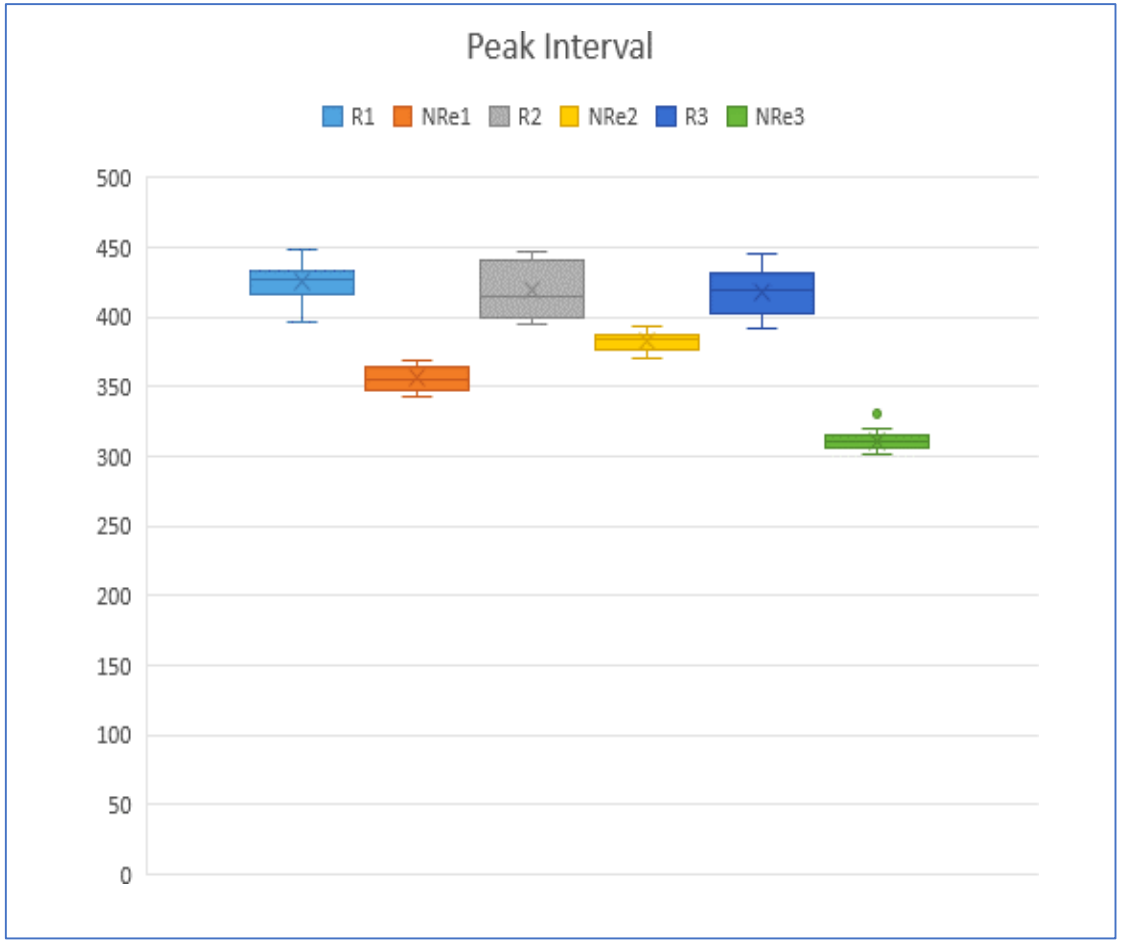


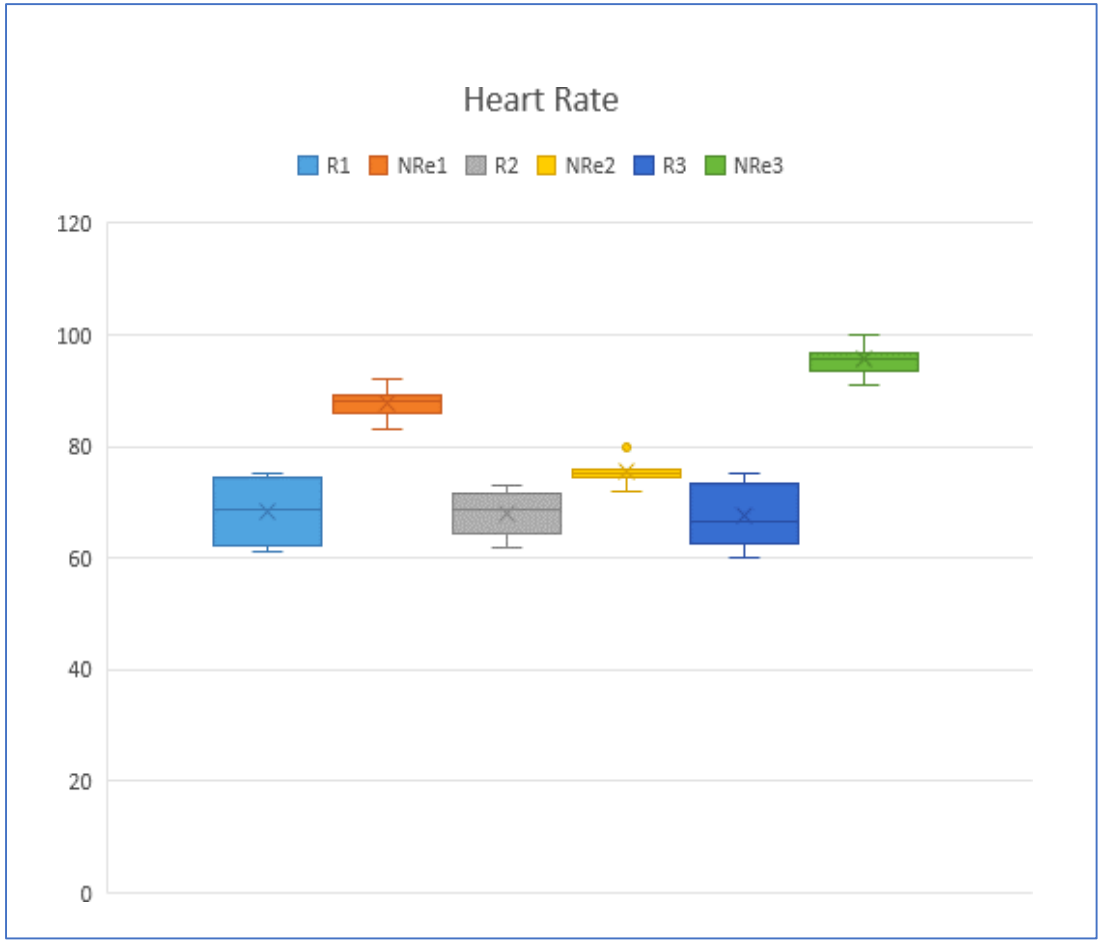









Peak Interval
R1
NRe1
R2
NRe2
R3
NRe3
500
450
400
350
300
250
200
150
100
50
0


Heart Rate
R1
NRe1
R2
NRe2
R3
NRe3
120
100
80
60
40
20
0

❑ Result of GSR Based Indication of Stress Stimuli:

$$Peak\ Rate = \frac{X_i - X_{min}}{X_{max} - X_{min}}$$

Where , X_i is peak rate one of the condition of each subject

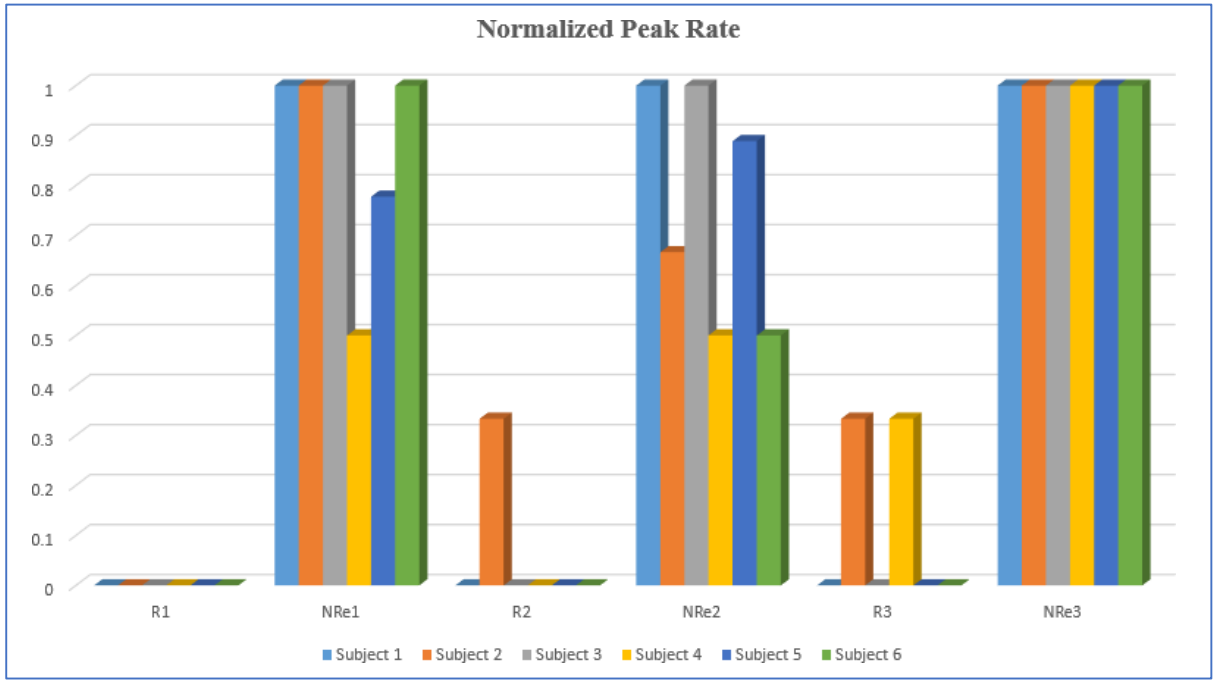
X_{max} is maximum peak rate of each subject

$X_{min\ is}$ minimum peak rate of each subject

Threshold value (T_h) around 0.38

Normalized Peak Rate from GSR Signal						
Subject	R1	NRe1	R2	NRe2	R3	NRe3
1	0	1	0	1	0	1
2	0	1	0.33	0.67	0.33	1
3	0	1	0	1	0	1
4	0	0.5	0	0.5	0.33	1
5	0	0.77	0	0.89	0	1
6	0	1	0	0.5	0	1
7	0	1	0	0.67	0	0.67
8	0	1	0	1	0	1
9	0	1	0	1	0.17	1
10	0.22	1	0	0.44	0	1
11	0	1	0.33	1	0.17	1
12	0	1	0	1	0	1

Table 16 Normalized Peak Rate from GSR Signal



Bar chart of Normalised peak of different subject in different stress condition

❑ Result of PPG based indication of stress stimuli:

Weighted KNN:

- Instead of a normal KNN classifier, we utilized a weighted k-nearest neighbors (KNN) approach with a k value of 5 for stress classification.
- Importance of k = 5 in the weighted KNN algorithm holds significance for Balance between local and global information

5 Crossfold Validation technique

		Actual class	
		P	N
Predicted class	P	TP	FP
	N	FN	TN

Accuracy=no of correct classification / total no of samples to classify

Sensitivity: It is the number of **P** cases that were correctly classified as such, divided by the total number of **P** cases **[TP/(TP+FN)]**.

Positive predictive value (PPV): It is the number of **P** cases that actually classified as **P** divided by the number of cases that the classifier classifies as having a **P** **[TP/(TP+FP)]**.

Specificity: It is the number of **N** cases that were correctly classified as such, divided by the total number of **N** cases **[TN/(TN+FP)]**.

Negative predictive value (NPV): It is the number of **N** cases that actually classified as **N** divided by the number of cases that the classifier classifies as being **N** **[TN/ (TN+FN)]**.

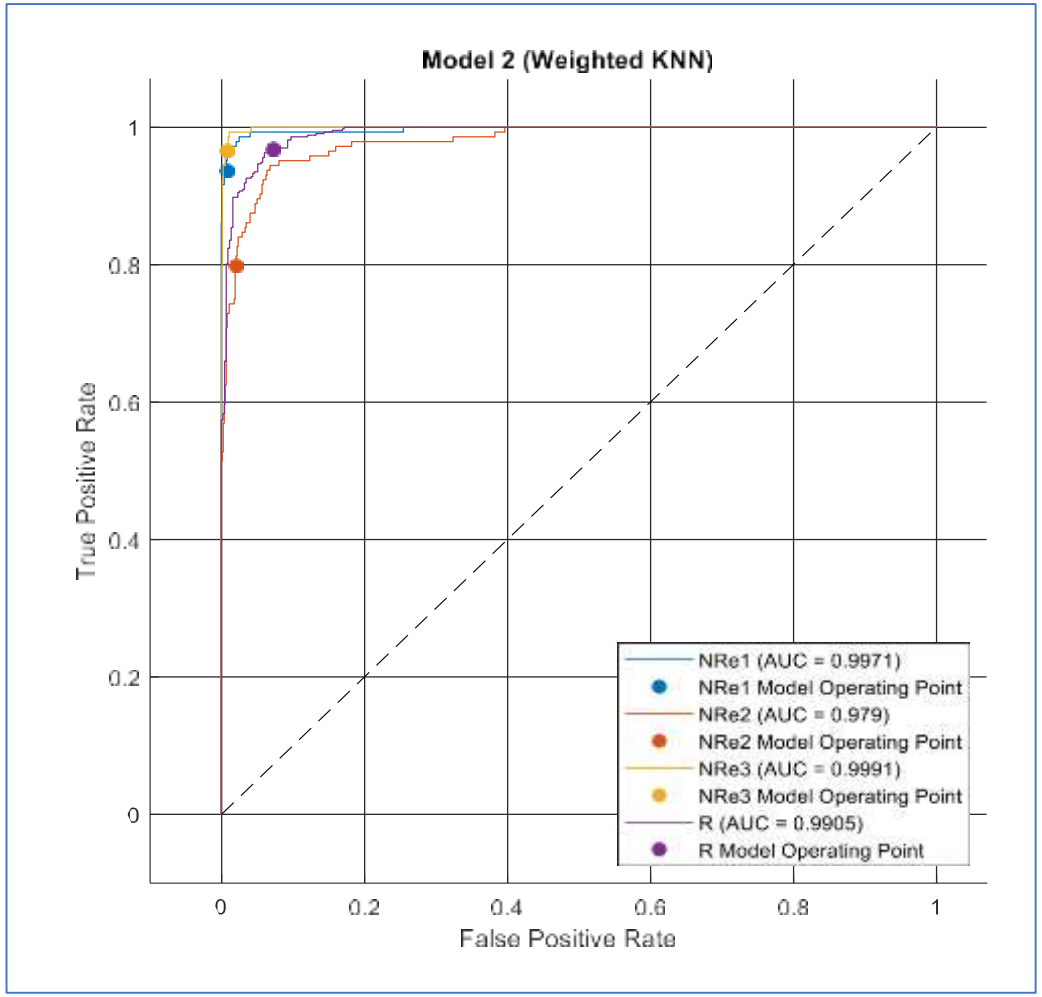
❑ Results of Classification:

Classification Type	No. of features	No. of Training Samples	No. of Testing Samples	TP	TN	FP	FN	Accuracy (%)	Sensitivity	Specificity	PPV	NPV
Resting vs Reading	12	230	58	142	130	14	2	94	0.98	0.90	0.98	0.98
Resting vs Listening Music	12	230	58	126	111	33	18	82	0.87	0.77	0.86	0.79
Resting vs Arithmetic Calculation Task	12	230	58	141	141	3	3	97	0.97	0.97	0.97	0.97
Resting vs All Non-Resting Condition	12	691	173	130	711	9	14	97	0.90	0.98	0.93	0.98

Classification Table

❑ Receiver Operating Characteristic (ROC) curve:

The ROC curve analysis reveals high accuracy for stress classification in all conditions, with an area under the curve (AUC) of approximately 0.99. However, the Listening Music condition shows a slightly lower AUC of around 0.97. These findings have significant implications for Health Mentoring purposes. Further research with larger subject samples is recommended to generalize the classification results for the given conditions.



ROC Curve of Resting vs. All Non-Resting Condition

❑ Advantages of Two State Classification:

- The two-state classification approach has several advantages like,
    i. Simplicity
    ii. Improved accuracy
    iii. Reduced complexity

- The use of PPG data in the non-resting state classification stage also has several advantages,
    i. High temporal resolution
    ii. Non-invasive
    iii. Wide applicability

Conclusion & Future Scope

Conclusion

Our project developed a GSR-guided PPG stress analysis system that accurately detects tasks based on stress levels. GSR signals act as markers for non-resting conditions, enabling binary classification. PPG features, analyzed using the KNN classifier, accurately identify specific stress-inducing tasks. The system offers comfortable finger-based data acquisition and has practical applications in clinical settings and stress analysis.

Future Scope

- Integration with wearable devices
- Long-term monitoring
- Multi-modal approaches
- Validation on larger datasets
- Clinical applications

THANK YOU FOR YOUR ATTENTION