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Framework for Stress Level Assessment using Biological Sensors

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Abstract--- Stress has become the new epidemic of the 21st century. While avoiding stress entirely is not possible because of modern-day life, strategies to cope with stress have been substantially investigated. However, fewer studies have used modern technological means to assess stress levels and concomitantly develop integrated ways to manage stress.

Keywords: Assessment, Biological Sensors, Framework, Stress Level

I. INTRODUCTION

Stress has been referred to as the new health epidemic of the 21st century, with costs on health care systems totaling $300 billion in the US alone. In the Philippines, several studies point to the fact that students in various academic fields experience stress related to their personal lives and academia, which may have serious consequences for their future mental and physical health. Various empirical studies connected stress with an array of mental illnesses that can manifest themselves in a relatively short period of time from stress exposure to disease onset. Other studies have demonstrated that stress can have long-term consequences of the physical health of people, including metabolic dysfunctions such as diabetes, cardiovascular diseases and endocrine malfunction. While these studies focused on self-assessment to determine stress levels and finaloutcomes of prolonged stress exposure, an objective measurement of stress levels is lacking from this literature. When assessing stress levels via self-assessment, participant perception and subjectivity may produce erroneous results.

Nevertheless, considering the way in which society functions today, avoiding stress entirely is an impossible task. A more feasible approach is stress management. Several tools that can help people manage stress do exist. These include the use of cognitive and emotional therapy which aids people in developing their own coping mechanisms, as well as the use of certain personalized therapies including scent therapy or music therapy. Music therapy, has been shown to have a viable effect on the autonomous nervous system (ANS) as well as on the endocrine system. The ANS controls body responses that are outside conscious control (i.e. blushing, sweating, heart rate etc.). When exposed to music, the ANS seems to respond via a parasympathetic pathway which induces a relaxation response. This mechanism was demonstrated to reduce the recovery time needed for the human body to return to normal parameters after a stress response. Most of these studies used as relaxing music samples to incite a relaxation response via the ANS classic music or the music preferred by the participant. Classical samples included Mussorgsky "Night on bald mountain", "Boccherini "Minuet", Tchaikovsky "Tchaikovsky Pathetique" and Allegri "Miserere". Studies also allowed for participants to control the volume of the music to the levels they were comfortable with. Conclusively, the research into music effects on ANS points to the fact that most relaxing music samples used are classical music and participant preferred music. Additionally, the participants should be able to adjust their own volumes as per to avoid the music becoming a factor of stress.

II. BACKGROUND OF THE STUDY

More recently, with advances in technology, means of measuring and managing stress have substantially improved. By using objective means for stress levels assessment, the subjectivity of self-reporting is eliminated, thus producing more accurate results. Various empirical investigations used different types of sensors and programming to aid students and other categories of people manage their stress levels. This seems to be a highly effective technique as one characteristic of the modern-day life refers to an increased amount of time, spend for work or entertainment, on the computer. Furthermore, data produced by Quartz indicates that in the Philippines, rates of laptop and PC use are 143 minutes per day. This number is surpassed only by Indonesia with the US beingsituated on the fourth position on top users. However, it must be considered that these numbers are overall averages, and it is possible that students and people working with computers far surpass this limit. Considering these arguments, it becomes plausible to approach stress management via computer-assisted technologies and sensory data.

Several studies demonstrated that Galvanic Skin Response (GSR) can function as an accurate indicator of stress. Electrodermal activity or GSR is based on the principles of human anatomy related to stress responses. GSR varies in accordance with sweat gland activity which is controlled by one of two main divisions of the ANS, the sympathetic nervous system (SNS). GSR and SNS function based on a direct correlation, whereby if experiencing a stressor, the SNS produces a series of chain reactions that also affect the sweat glands, which in return produce variations in GSR. In terms of practicality GSR Arduino based models are not only simple to use and integrate but also cost-efficient and easy to maintain.

Other studies used Photoplethysmogram (PPG) as an indicator of stress levels. This procedure relies on the same

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ANS reaction to stress, yet in this case, the measurement focuses on the increase in blood flow to the derma which is measured via pulseoximetry. The underlining mechanism of this measurement relies on the changes registered in the volume of arteries. Research using PPG and GSR for stress detection generally used these methods in combination with other indicators of stress.

III. SCOPE AND LIMITATION

Several limitations can be identified in the current study. First, it is to be considered that human regulatory stress response capacity is regulated by the number of cortisol receptors present in the brain. This is a variant which for some people results in better stress management while for others in poor stress management. Since the sample will not be assessed for biological stress management capacity, the research cannot account for this confounding factor.

Finally, the scope of this study is to determine if PPG and GSR sensory data are effective in assessing stress levels in the human body and if music can help reduce the time needed for the body to return to the pre-stress state. This implies that the study will not measure other stress indicators or assess the quality of the sensors used. Furthermore, the study will not test for personalization and preference of the music used in the experiment.

IV. GENERAL OBJECTIVE

The aim of this study is to develop an Arduino-based framework for assessing and regulating human stress response. Several objectives have been developed to reach the aim of this research:

1. To develop a functioning stress assessment module that can collect data from the subject.
2. To develop a functioning stress assessment module that can analyze stress data from the subject.

V. STATEMENT OF THE PROBLEM

While stress cannot be eliminated, stress management strategies do exist. Technological means of managing stress have only recently begun to be explored. Noting that people in the Philippines spend a significant amount of time in front of the computer, stress reduction strategies via this method may be more effective and time-feasible in reducing stress than therapeutic approaches. A stress reduction strategy is proposed, which will use PPG and GSR monitoring to detect stress levels.

Based on the proposed investigation, the study will attempt to solve the following problems:

1. How will the developed framework for stress level assessment collect data on stress level indicators from the user?
2. How will the proposed framework for stress level assessment analyze the collected input to trigger a stress reduction intervention?

VI. CONCEPTUAL FRAMEWORK

The current study is based on a biological theoretical framework of stress, aiming to modify the ANS stress response and thus reduce the time in which the human body is subjected to stress. To develop the conceptual framework for this study, the General Adaptation Syndrome (GAS) model developed by Hans Selye (1950) will be used. The model assumes the normal state of the organism as homeostasis. In this state, the body produces normal biological responses, in the absence of an external stressor. As argued by this model, organisms respond to stress in three stages. In the first stage, the body detects a stressor which sets the Alarm Phase. Following this stage, the body begins to produce adaptations to stress, which include increase sweat glands activity and increases in heart rates and pulse. This is referred to as the Resistance Phase, in which the body produces adaptations to stress via the ANS pathway. Following the body's response through adaptation means, the body can enter either the Recovery Phase in which the organism's compensatory mechanisms reduced the stressor, or the Exhaustion PhaseIf the body enters the exhaustion stage, then the ANS produce recurring symptoms of stress which include increased sweating and heart rate, increase respiratory rate and other biological responses which eventually deplete the resources of the organism. For the current study, this indicates that in the control stage, the body will continue to give out readings of stress indicators of PPG and GSR sensors.When the body remains for a prolonged period in the exhaustion stage, irreversible health damages are observed. Some studies have used this model to predict the onset of various diseases, including gastro-duodenal ulcers.

This literature indicates that GAS can provide a general understanding of the stages of a stress response. As a result, this theoretical framework will be used when approaching the development of this study. As listed in the figure below, the scope of RM is to induce a relaxation response in the ANS, which in return will minimize or reduce completely the stress responses of the body registered in the resistance phase. It is expected that this intervention will reduce the regression of the body's stress responses to the initial homeostatic state. Figure 1 below presents the conceptual framework used in developing this study.

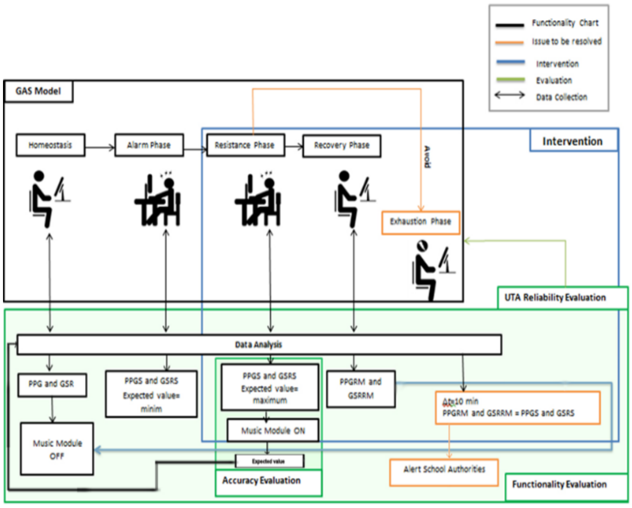

Figure 1 –Conceptual Framework

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As illustrated the proposed framework can monitor stress levels in students as well as provide an intervention to decrease stress levels and evaluate the efficiency of this intervention via the recorded values. As illustrated by the theoretical framework, the exhaustion phase is one of two possible outcomes, the second of which is the recovery phase. When a prolonged state of exhaustion is present, this can result in illness for the subject. Hence, the intervention seeks to disrupt the ANS response initiated during the resistance phase and promote a return to homeostasis levels by engaging in the recovery phase when the body is exposed to relaxing music. When the recorded values under relaxing music will be equal to the values under stress, the school authorities should receive an internal message to alert them of the stressed state of the student.

VII. SIGNIFICANCE AND BENEFITS OF THE STUDY

This study seeks to build on previous literature attesting to the efficiency of PPG and GSR to detect stress in humans. The scope of this study will thus be to construct a model for stress level assessment in students and introduce a stress management component represented by relaxing music. This study will benefit the following:

1. Tertiary Schools will benefit from the developed model by achieving an increased awareness of their student’s stress levels and intervene promptly to reduce the student’s stress levels and avoid exhaustion.
2. Teachers/ Professors/ Practitioners will benefit from the developed model by achieving classrooms with students that are less exhausted, more able to learn and less likely to miss out on classes due to exhaustion. This may also increase class participation and provide higher academic achievements.
3. Students will benefit from the proposed model by minimizing their stress levels and avoid reaching the exhaustion phase of the GAS theoretical model. This may contribute to a better learning experience and higher academic achievements.
4. Other researchers can build on the proposed model and provide contributions to testing the effectiveness of PPG and GSR sensors used in combination for assessing stress levels. The model could also be developed to serve other types of beneficiaries, such as working populations.

VIII. REVIEW OF RELATED LITERATURE AND STUDIES

Several studies [1], [2],[3] used GSR sensors to measure stress responses. This research employed experimental designs to test various systems for measuring stress by using GSR alone or combined with additional methods. Nevertheless, some indications [3] point to the fact that the sample needs to be pre-tested under normal and stress conditions prior to the experiment to achieve unbiased measurements. As listed by this research, the GSR variation is between 10 kΩ and 10 MΩ. As standard sensory procedures, GSR is measured units of micro-Siemens (μS) and achieved based on average values of the subject tested. Hence one measurement is not sufficient, and a mean of values needs to be calculated for everyone[4]. Normal values of GSR have been noted as 7.5 μS with a rise time of the phasic GSR listed at 2.12 μS [5].

In terms of assessing the capacity of GSR to be an accurate assessment tool for stress, various studies demonstrated that this method holds the capacity to generate a real-time correlation with stress factors because of the direct link between increased sweat levels and increased conductance of the skin concomitant with a decrease resistance [6]. [7] demonstrated this property of GSR as early as 2005 by comparatively testing additional methods including respiration and heart rate. This research calculated that the lowest accuracy rate for predicting stress levels by using GSR is 94.7% while the highest accuracy rate attained was 100%. A similar study conducted [8] found contrasting results and suggested that heart rate and speech indicators are better predictors in comparison to GSR. However, [9] noted an accuracy rate of 99.5% in stress prediction when using GSR and heart rate measurements. The study used an experimental design in which individual measures were taken from the sample and compared with normal and stress conditions.

Conclusively, this research indicates that GSR can be an accurate measurement of the body’s stress response. However, individual measurements need to be taken for subjects and normal values registered and compared under stress. The reason for the necessity of this procedure relies on the fact that individuals have personal variations in GSR, which thus indicates that no standard values can be used. Another observation that can be made in this case is that GSR may produce better results when combined with other measurements of stress levels as indicated [9].

Other experimental design studies [10], [11] tested the efficiency of PPG to function as a stress indicator. [12] used PPG in combination with ECG (electrocardiogram) and pupillometry (PD) to determine if these measures can predict stress levels. Data were imported via a Fuzzy SVM (FSVM) for all three measures. The study determined that when used together, these sensory data can produce accurate reflections of stress states of subjects. A simple technique to retrieve PPG values is by using sensors that measure blood volume changes in the microvascular system. The sensor uses an infrared source and measures the infrared light quantity which is not absorbed as wavelength hertz measures [13].

IX. PRESENTATION, ANALYSIS AND INTERPRETATION OF DATA

In this section, the specified approach will be enumerated as an answer to the specific questions, and discussed how it was applied in this research in non-statistical way.

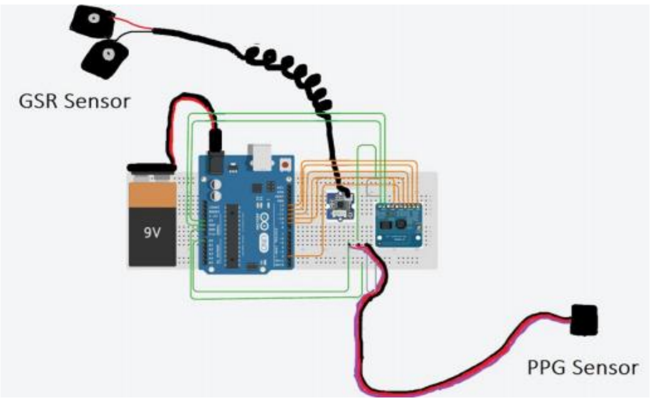

Figure2–Circuit Diagram Model

The Arduino circuit was developed based on ISC (2016) modeling, to which a music module is attached. As shown in Figure 4, the circuit consists of two wearable sensors an Arduino UNO R3 microcontroller and a BLE module. Optionally, the design may require a 9V battery and a Basic Grove Shield with identical I/O pins as UNO R3. To measure PPG, a Pulse Sensor AMPed is used, while for GSR a Seed Grove GSR sensor is used (ISC, 2016).

Algorithm Discussion

To develop an Arduino module for monitoring stress levels, a Böhm-Jacopini structures algorithm is proposed. This algorithm was developed based on three main control structures listed as sequential execution, selection and finally, iteration. In the sequential execution phase, also referred to as the execution, the program executes a series of functions in the exact order in which they are written. In this case, the sensors involved in stress monitoring and their corresponding coding sequences will register the values picked up from the participants. In the second stage, the selection process focuses on extracting which logic expression (true or false) determines which statements will be executed in stage 3. In this case, the value of true will be represented by both sensors pick up stress specified values, while the false statement will be represented by normal values recorded by the device from both sensors. In phase 3, iteration structures are used to execute a series of statements, which are identical in a loop, until specified conditions occur. In the present case, playing music until stress levels are recorded to initial homeostasislevels. The algorithmic representations in this case follow a flowchart display with GOTO (IF test=true THEN GOTO step X) structures, where X is a specified step in the algorithm, in this case playing music. A graphic illustration of the algorithm is presented. In this illustration, rectangles represent the steps involved in a process. The diamond shapes represent branching out functions that allow the system to do one or multiple actions from a set of pre-determined steps.

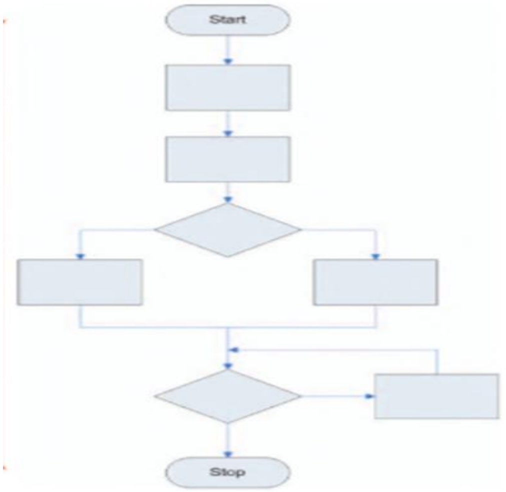

Figure 3– Böhm-Jacopini structures algorithm

The module will function based on data sensory input registered from participants via the PPG and GSR sensor which will measure homeostatic levels (no stress condition noted as PPG and GSR) and stress levels (noted as PPGS and GSRS) in a small sample. Minimum and maximum values will be recorded. The mean value of minimal readings in normal conditions and the mean of maximum values recorded in normal conditions will be used as normal range values for the audio system to be turned off to avoid system errors on reading. Minimum and maximum mean values recorded in the stress conditions (PPGS and GSRS) was used as values to trigger the audio module. Another set of values was recorded for PPGRM and GSRRM, which measure the body's stress response when the audio module is turned on for a period of 10 minutes. It is expected that the PPGRM and GSRRM values is as close as possible to the values recorded in normal conditions. These values were used to induce a stop response from the audio module, until the system detects PPGS and GSRS values again when the audio module is triggered again.The figure 4 below displays the flowchart algorithm for the development of the Arduino circuit.

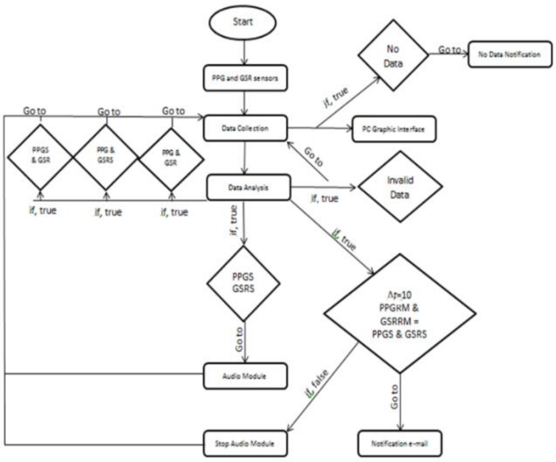

Figure 4–flowchart algorithm for the development of the Arduino circuit

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Framework for Stress Level Assessment Algorithm
Input:

The PPG value array (n x 1) and GSR value array (n x 1) with 0 initial values where n is several sectors to be pipelined.

(This is one-dimensional array)
GSR_Value array (n x 1)
GSR (g1, g2, g3… Gn)
PPG_Value array (n x 1)
PPG (p1, p2, p3… Pn)
Denoising for both signal of simple low pass filter.
y (n) = x (n) + x (n-1)

Preprocessing & Result:

For GSR {} and PPG {}, calculate RMS (GSR {}) for average level of skin conductance voltage form and RMS (PPG {}) for average level of pulse voltage form

$$x_{rms} = \sqrt{\frac{1}{n}\left(x_1{}^2 + x_2{}^2 + \cdots + x_n{}^2\right)}$$

$$RMS_{Total} = \sqrt{RMS_1{}^2 + RMS_2{}^2 + \cdots + RMS_n{}^2}$$

Update RmsGSR {} values when the next pipeline arrives.

Eliminate top 10 max values and 10 min values in GSR (g1, g2, g3… Gn) andPPG (p1, p2, p3… Pn)
Set nn <- n/ 10;
{MaxGSR {a1, a2… A10} = {max {GSR (I x nn, (i+1) x nn)}
{MinGSR {a1, a2… A10} = {min {GSR (I x nn, (i+1) x nn)}
{MaxPPG {a1, a2… A10} = {max {PPG (I x nn, (i+1) x nn)}
{MinPPG {a1, a2… A10} = {min {PPG (I x nn, (i+1) x nn)}

Original number of arrays that come to the program is 500 for this device.
So, in GSR (g1, g2, g3… Gn), n equals 500.
In each of this array, I also divide these 500 arrays into 10 parts.
nn <- n/ 10; (Here nn = 500/10 = 50;
In each small array (nn = 50), I calculate maximum value and Min value.
Then 10 small arrays ------- 10 Min values and 10 Max values.
{MaxGSR {a1, a2… a_{10}} = {max {GSR (I x nn, (i+1) x nn)}
{MinGSR {a1, a2… a_{10}} = {min {GSR (I x nn, (i+1) x nn)}
{MaxPPG {a1, a2… a_{10}} = {max {PPG (I x nn, (i+1) x nn)}
{MinPPG {a1, a2… a_{10}} = {min {PPG (I x nn, (i+1) x nn)}

Repeat:

Initialize Rms (GSR {}), Rms (PPG {}), to eliminate top ten max values
and min values and replace it as RMS value of each pipeline
SUM (Max (GSR (a1, a2, ……, ann)) ← Rms (GSR {}), I = 1, nn
SUM (Max (PPG (p1, p2… pnn)) ← Rms (PPG {}), I = 1, nn
Set the threshold conductance value GSR_Thr = Threshold_init
If RMS (GSR {}) > GSR_Thr Stress_level ← High
Else Stress_level ← Low
For PPG Sensor
Detection of R peak values for PPG sensor signal.
It shows the R-R intervals labeled A = (R-R) 1, B = (R-R) 2, C = (R-R) 3… (R-R) it represents the interval between two neighboring QRS peaks.
The RMSSD is looking for the successive difference between the intervals meaning:
A-B à(R-R)1 – (R-R)2
B-C à(R-R)2 – (R-R)3…and so forth
The RMSSD calculates to:

RMSSD

$$= \sqrt{\frac{1}{N-1}\left(\sum_{i=1}^{N-1}\left((R-R)_{i+1}-(R-R)_i\right)^2\right)}$$

Where **N = number of RR interval terms**

$$\text{RMSSD} = \sqrt{\frac{1}{N-1}\left(\sum_{i=1}^{N-1}\left((R-R)_{i+1}-(R-R)_i\right)^2\right)}$$

In this equation, RMSSD is just for measuring these variabilities.
If RMSSD (PPG (b1, b2 … bn)) > Thr
Stress_level ← High
Else Stress_level ← Low
Set the next pipelined arrays for PPG, GSR.
Final_Stress_Level = GSR_Stress *0.6 + PPG_Stress * 0.4

End repeat:

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