ECG BASED STRESS DETECTION USING COVOLUTIONAL NEURAL NETWORK

BY

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ABSTRACT

Stress refers to a man's ability to respond to any external or internal threat or pressure and has a direct or indirect impact on one's health. Hence, there is a growing need to detect stress at an early stage as one might not know whether he/she is stressed or not, and stress left undetected for a long time can become chronic and life endangering. Many health-related disorders are linked to stress and thus monitoring, measuring, and managing stress is simply a lifesaving remedy. There are so many physiological methods to measure stress, however, the issue with most of those physiological methods is the complexity in measuring the signals and the methods are not convenient for day-to-day use. This study implements the use of Electrocardiograph (ECG) signals which are recorded using a RAQIB smartwatch and does not need any second person intervention. Features extracted from the ECG signals have been the key to detect stress for many years, however, recent advancements in neural networks have prompted us to apply the convolutional models as well apart from the traditional machine learning approaches. Researchers are rapidly moving towards the neural networks approach due to the automatic ability of these neural networks to learn features and due to higher accuracy classification models of Convolutional Neural Networks (CNNs). Based on the advantages of CNNs over the traditional machine learning approaches, this study based on the two-dimensional CNN model is proposed for the detection and classification of ECG signals into two distinct classes: namely, stress and no-stress. It is the first such study for stress detection where the one-dimensional ECG signals are converted into 2-D scalogram images by virtue of a Continuous Wavelet Transform (CWT). The proposed CNN model consists of an input layer to feed a scalogram image followed by 4 back-to-back layers of convolution, rectified linear unit (RELU) and max pooling. The accuracy of the proposed stress detection model is compared with both the handcrafted features approach and other relevant models. The average accuracy of 99% is certainly better than the traditional approaches for detecting stress and the usage of the smartwatch makes the model more robust and easier to use while performing day to day activities. The model can be easily and conveniently used at workplaces and offices to determine stress without any assistance from a second person and the method is quick.

خلاصة البحث

يشير الاجهاد إلى قدرة الرجل على الاستجابة لأي تهديد أو ضغط خارجي و داخلي، وله تأثير مباشر و غير مباشر على صحته. لذلك، هناك حاجة متزايدة لاكتشاف الاجهاد في مرحلة مبكرة، إذ قد لا يعرف المرء ما إذا كان قد تعرض للاجهاد أم لا، كما أن الإجهاد الذي لا يتم اكتشافه لفترة طويلة يمكن أن يصبح مزمنا وقد يعرض حياة الفرد للخطر. ترتبط العديد من الاضطرابات الصحية بالاجهاد، وبالتالي فإن مراقبة الإجهاد وقياسه وإدارته يشكل علاجا منقذا للحياة. ومع ذلك، هناك الكثير من الأساليب الفسيولوجية لقياس الاجهاد، ولكن المشكلة في معظم هذه الطرق الفسيولوجية هي التعقيد في قياس الإشارات والأساليب غير الملائمة للاستخدام اليومي. تطبق هذه الدراسة إستخدام إشارات ECG المسجلة باستخدام تقنية (RAQIB) ولا تحتاج إلى تدخل شخص آخر. إن الخصائص المستخلصة من إشارات ECG كانت هي المفتاح لاكتشاف الإجهاد لسنوات عديدة، ومع ذلك فإن التطورات الأخيرة في الشبكات العصبية دفعتنا إلى تطبيق النماذج التركيبية بعيدا عن نهج التعلم الآلي التقليدي. ونظرا للقدرة التلقائية للشبكات العصبية (السي إن إن) على التعلم، تقترح هذه الدراسة وبالإستنادا إلى نموذج السي إن إن الثنائي الأبعاد اكتشاف وتصنيف إشارات ECG في فئتين: وهما الاجهاد، واللاجهاد . وهي أول دراسة من هذا النوع لاكتشاف الاجهاد بحيث يتم تحويل إشارات ECG أحادية البعد إلى صور رسم بياني D-2 بفضل تحويل الموجات المستمرة CWT. يتكون نموذج CNN المقترح من طبقة إدخال لتغذية صورة الرسم البياني متبوعة ب 4 طبقات من التفاف والوحدة الخطية الصحيحة (RELU)، والتجميع الأقصى. وتقارن دقة نموذج الكشف عن الاجهاد المقترح مع كل من نهج السمات اليدوية والنماذج الأخرى ذات الصلة .إن متوسط الدقة الذي يبلغ 99٪ هو بالتأكيد أفضل من الأساليب التقليدية لاكتشاف الاجهاد واستخدام الساعات الذكية يجعل النموذج أكثر فاعلية وسهولة في الاستخدام أثناء أداء الأنشطة اليومية. بحيث يمكن إستخدام النموذج بسهولة و سرعة في أماكن العمل والمكاتب لتحديد الإجهاد دون أي مساعدة من شخص آخر.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science (Computer and Information Engineering)

Rashidah Funke Olanrewaju
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DECLARATION

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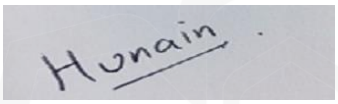
Signature  Date 10/Dec/2021

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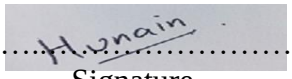

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Firstly, it is my utmost pleasure and honour to dedicate this work to my dear parents and my family, who granted me the gift of their unwavering belief in my ability to accomplish this goal: thank you for your support and patience. Thank you for letting me walk on the path I always wanted to.

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LIST OF ABBREVIATIONS

ANN	Artificial Neural Network
AP	Absolute Power
CNN	Convolutional Neural Network
CWT	Continuous Wavelet Transform
DWT	Discrete Wavelet Transform
ECG	Electrocardiography
KNN	K-Nearest Neighbors
LDA	Linear Discriminant Analysis
LR	Logistic Regression
ML	Machine Learning
NB	Naïve Bayes
PSS	Perceived Stress Scale
RP	Relative Power
SGD	Stochastic Gradient Descent
SVM	Support Vector Machine
WEKA	Waikato Environment for Knowledge Analysis

LIST OF SYMBOLS

s	Scale parameter (dilation)
ω	Translation parameter
$x\ (t)$	Position of wavelet at time t
$\Psi(t)$	Wavelet function
dt	Change in time
$e^{j\omega ot}$	Position in complex number domain
$e^{t^2/2}$	Position in real number domain
C	Normalization factor
ds	Change in scale parameter
dw	Change in translation parameter
$\Psi Morl(t)$	Morlet wavelet
σ^2	Gaussian constant

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Stress is commonly referred to as pressure or burden. Normally, people experience pressure in one way or the other during the day-to-day activities and this pressure can be related to physical, emotional, or psychological changes. Response to a stressful event depends on how an individual views the situation and depends on his or her general physical health. However, factors such as genetical or any tragedy during childhood or even in the womb can cause someone to overreact to stressful situations. Over reacting and other habits such as smoking, drinking, not exercising can also increase the risk of negative effects of stress.

'Allostasis' is the process of how the body responds to stress, whether the stress is an acute (short-term) stress, or a chronic (long-term) stress (Sriramprakash et al., 2017). When individuals feel threatened, there is an acute stress response known as "fight or flight" reaction. This response will make the body release several stress hormones such as cortisol and adrenaline into the bloodstream. The hormones improve our concentration, ability to react and strength. Besides that, our blood pressure and heart rate will get increase while immune system and memory getting sharper. Chronic stress, which is a long-term stress, will cause a big problem in the long run. If an individual is facing burdens or challenges repeatedly, his body will produce a lot of hormones and the body does not have enough time to recover. It can also cause serious health problem (Sriramprakash et al., 2017). Changing of body's reaction somehow can be very helpful when it happens for a short period. But if the

body's response is for a long time, it will result in the production of many hormones which can affect our health. The long-term effect of chronic stress can cause health problems such as indigestion, obesity, weak immune system, nervous system issues and cardiovascular imbalances.

Stress also can cause psychological conditions such as anxiety, personality disorders and depression. According to a World Health Organization (WHO) report, 300 million people around the world suffer from depression and most of them also have symptoms of anxiety (*Some 300 million people,2017*). A recent study by them also stated that depression and anxiety disorder has caused lost in productivity of US$ 1 trillion each year in the global economy (Greenberg et al., 2015). Based on this statistic, we can conclude that stress does not only affect individuals, but it can cause catastrophic impact to the society.

Stress can come in many ways depending on where we live. As per the Global Emotions Report 2019, the research was successfully conducted to determine stress levels of individuals from as many as 143 countries and it was found that just over one-third of people said that they experienced "a lot of stress". Greece is the most stressed country with 59% of people surveyed there said they are under a lot of stress. Greece, which topped the list with 59% individuals feeling stressed, was followed by Philippines and Tanzania that had stress levels among 58 and 57 % of the individuals respectively (G.C Bao, 2019). We do have some stress related statistics from Malaysia. Study conducted by the Malaysian by the Ministry of Health among the teenagers (Figure 1.1) shows that 1 out of 10 are stressed and 1 in 5 are depressed. Another study that investigated workplace hazards revealed that 53% of Malaysians even at the healthiest workplace have at least one dimension of work-related stress (Malaysia's Healthiest workplace, 2019).

Figure 1.1 Survey among Malaysian Teenagers. (Malaysian Ministry of Health, 2017)

Stress has become a severe troublemaker that has affected many human beings with distinct professions, lifestyles, and age categories. Stress can lead to harmful illnesses directly, or indirectly. It is highly important to motivate people to adjust their lifestyle or start practicing stress management. During many years in a university, a lot of students are exposed to different kinds of stress, especially during tough phases such as final exam weeks or any project deadlines. It is rather a fact that the complete avoidance of stress is impossible. So basically, if people are informed of their stress levels, they become empowered in taking some pre-emptive actions to alleviate stress. It is becoming more popular practice to promote healthier lifestyle to students, give advice regarding safety and security, eating well, anger management, dealing with emotional abuse or culture shock, overcoming loneliness, and alike. However, still not that much is done to systematically monitor the levels of stress that students experience. In the current practice students often get help only when the problem becomes severe and may require psychological or medical help.

However, stress level also can be detected by our heart rate, electrocardiography, and blood pressure in the body. So, the aim of the project is to

develop a measurement system called the rapid smartwatch-based stress detection system using the FavorIot platform. From that measurement, we can analyze the level of stress occurred on a person.

1.2 PROBLEM STATEMENT

Stress is no doubt the one of the major problems' humans are facing nowadays. It is a mixture of mental, physiological, and physical responses or reactions of a human mind to his/her day-to-day activities. People in stressed state generally are accompanied with rapid changes in heart rates, deflections in Skin Responses, fluctuating Blood Pressure (BP), hypertension and Pupil Diameter (PD). So, to detect or measure the levels of stress, it is vital to determine physiological measurements. Stress can be basically considered as one of the emotional reactions to varied scenarios or situations a human has been put in and stress conditions for one might be normal for the other. Hence, there is a growing need to detect stress at an early stage as one might not know whether he/she is stressed or not, and stress left undetected for a long time can become chronic and life endangering.

Stress detection based on physiological signals has been researched for many years now and is actively researched as well. Research works dealing with the physiological data for the interpretation of physiological states are of particular interest for this study. The problem in hand is more about the accurate classification of physiological states or reactions of humans during different scenarios. It is indeed a classification problem where an appropriate classifier would eventually classify the ECG signals into stressed or no stressed state and stress further could be classified as low stress and high stress states. Due to simplicity, interpretability, and speed of linear classifiers (Kantorov and Laptev, 2014), these classifiers form an important

and crucial class of classification technology. However, when it comes to the classification based on signal features, non-linear classifiers (Ghosh et al., 2019) are most appropriate.

Another problem is the choice of the devices used to collect ECG signals. Most of the studies have used sticky electrodes (Giannakakis et al., 2019) to collect ECG samples which are simply not feasible for office use and these kinds of methods need assistance from a second person for sample collection. There are also few studies that have collected data from online databases (Li and Liu, 2020) and performed classification which cannot be relied upon completely due to anonymity of many of the participant conditions. We are thus in need of a somewhat realistic, convenient, accurate, and rapid stress detection mechanism which can be easily implemented at homes, offices, and many other places.

1.3 RESEARCH SIGNIFICANCE

Stress is how your body reacts to any kind of demand or threat. When the body feels stress, hypothalamus which is the tiny region in the brain signals your adrenal glands to release a surge of hormones which include adrenaline and cortisol into the bloodstream. As these hormones are released the liver is triggered to produce more blood sugar which gives you an energy kick and breathing becomes more rapid and heartbeat and blood pressure rises. If the stress is caused by physical danger, then the released chemicals can be beneficial as they give you more energy and strength and also speed up your reaction time and enhance your focus. But if the stress is caused by something emotional it can be harmful because there is no outlet for this extra energy and strength. Once the source of stress has passed hormone levels return to normal as do heart rate and blood pressure and other systems also returned to normal. Recent stress statistics (Boyd, D. (2020, June 16)) show the top seven causes of

stress in the US to be: (i) job pressure, (ii) money, (iii) health, (iv) relationships, (v) poor nutrition, (vi) media overload and (vii) sleep deprivation. All of these are the emotional kind not the physical danger that can be beneficial. Other statistics (Stress Research. (2020, June 16).) show 77% of people regularly experienced physical symptoms caused by stress, 54% of people say stress caused them to fight with people close to them and 30% of people say they are always or often under stress at work. Long-term activation of the stress response system can cause major problems such as anxiety, depression, digestive problems, headaches, heart diseases, sleep issues, weight gain and memory and concentration impairment. It is vital for every health-conscious human being to learn about the levels of stress present that would initiate the necessary checks and balances if the levels of stress are high. So, our main goal through this research is to make the individuals aware about the presence of stress so that appropriate actions can be taken on time.

1.4 RESEARCH QUESTIONS

In contribution to this research project, the following research questions have been developed based on the objectives and goals of this research:

RQ1: What are the ECG data features that give the best possible results for various classification techniques?

RQ2: Can ECG can help in identification of stress during day-to-day activities?

1.5 RESEARCH OBJECTIVES

The main aim of this project is to detect stress in individuals. The overall objectives of this work can be put as following: -

1. Analyze ECG signals for extraction of features relevant for stress classification.

2. Classify ECG signals into stress and no stress states based on the machine learning classification algorithms.

3. Develop convolutional neural network model that would detect the presence or absence of stress in individuals with a very high accuracy.

1.6 RESEARCH SCOPE

This research is carried on the data taken from the smartwatch and will mostly be applicable to such wearable devices. All the findings of this research have been taken from ECG samples at a frequency of 120Hz and this value of frequency is set by developers of this smartwatch. It will be interesting to know if the findings remain unchanged or not at higher frequencies. ECG samples obtained were also collected at room temperatures and the wrists were completely dried prior to the usage of RAQIB smart watch. Conventional way of collecting the ECG samples makes use of 3 electrodes and the application of electrode gel which is no way a convenient and rapid stress classification procedure that can be used at workplaces and involves the second person to record the data. On the other side, the wristwatch used for this research is a single electrode device which can be conveniently and swiftly used at offices and workplaces to record ECG data.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

In this section, the general information on electrocardiogram signal and stress will be briefly elaborated. We will also be discussing about the contribution of other researchers in the field of stress detection by virtue of physiological signals.

2.1.1 Electrocardiography (ECG)

An electrocardiogram also known as ECG is a test that measures the electrical activity of the heartbeat. With each beat, an electrical impulse travel through the heart. This wave causes the muscle to squeeze and pump blood from the heart. A normal heartbeat on ECG will show the timing of the top and lower chambers. There is a "P wave" which yields from a right and left atria or upper chambers (Hossain et al., 2019). Then it is followed by a flat line when the electrical impulse goes to the bottom of chambers. The "QRS complex" is the next wave that produced by right and left bottom chambers. The final wave or "T wave" represents electrical recovery or return to a resting state for the ventricles (Elgendi et al., 2016).

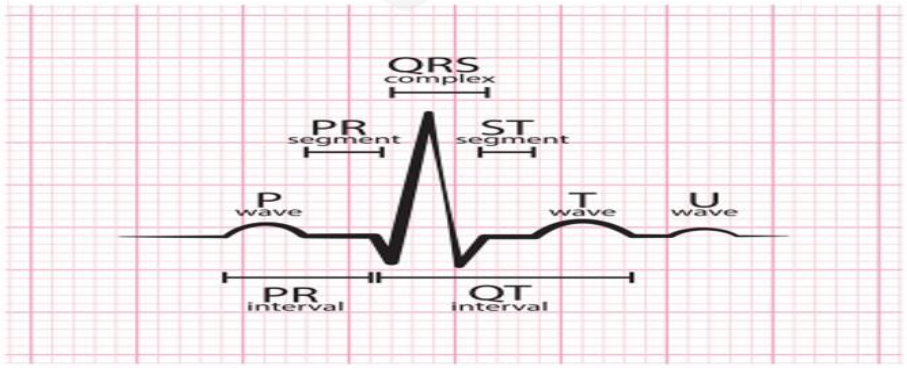

Figure 2.1 Normal Electrocardiography wave (Pandit et al., 2017)

The segment between the QRS and T waves can show an elevation when ECG detects a severe or urgent heart attack. Smaller heart attacks sometime show signs, but not always. The ECG is good for detecting arrhythmias, which are abnormal rhythms. The most common arrhythmia is atrial fibrillation. This is where the top chambers (the atria) do not squeeze properly. As a result, blood can stagnate and form a clot, which can then go to the brain and cause a stroke (Fauchier et al., 2016). So, as someone is in the stress state, the QRS and T waves will reach a higher point. Figure 2.1 shows the different waves, segments, and intervals of an ECG signal.

Based on the research paper (S. McStay,2019), a conventional method of recording ECG signals is to use 12 lead electrodes that are placed at the patient's limb and at the surface of the chest. Then, the magnitude of heart's electrical potential will be measured from 12 different angles and the time is recorded in 10 seconds. At this moment, overall, of direction and magnitude of the heart's electrical depolarization is captured.

An ECG can show huge information about the heart's structure and its function in an electrical conduction system. Besides that, the signal also used to measure the rhythm and rate of heartbeats, the position and its size of the heart chambers, the mark of any breakdown to the heart's muscle, the effects of cardiac drugs, and the function of implanted pacemakers.

Many researchers have used ECG signal for stress detection. There are other studies that used an ECG signal to detect stress levels. Compared with the Blood Volume Pulse (BVP), the ECG signal can provide a more precise determination of the heart rate by the detection of the sharp R peaks (Lin et al., 2015).

2.1.2 Stress

Mental stress occurs when our body reacts to a change that needs physical, mental, or emotional adaption. In 1934, the father of stress research, Hans Selye introduced a model called General Adaption Syndrome (Tan et al., 2018). This model represents three phases of stress as can be seen in Figure 2.2. The first stage is an initial alarm stage where the hormonal reaction is a fight or flight stress response. Our body response this way to maintain balance by activating Hypothalamic- Pituitary Adrenal (HPA) axis, the Sympathetic Nervous System (SNS) and the adrenal glands. During this time, our body releases the stress hormones such as cortisol, adrenaline, and

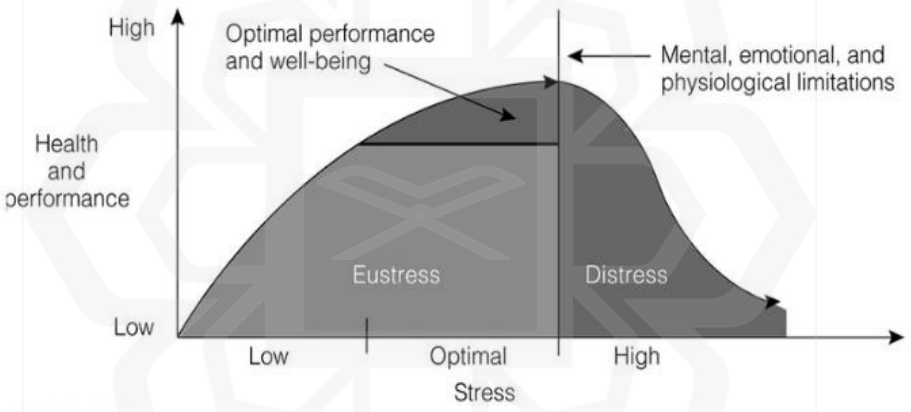

Figure 2.2 Relation Between Stress and Health (Tan et al., 2018)

noradrenaline to provide instant energy. If the stressful condition continues, it will move on to the second phase which is the resistance stage. During this time, the body will try to adapt by a continuous effort in resistance and remains in a stage of arousal which is called as 'Eustress'. From this model, we can understand that stress can cause many diseases as it causes long-term chemical changes if our body is continuously exposed to stress. This is because, our body does not have a limitless supply of energy to adapt to stressful state. Therefore, stress detection is very important as it can help us to avoid stress related health problem (Tan et al., 2018).

2.2 MACHINE LEARNING

We are living in a world of humans and machines and humans have been evolving and learning from the past experiences since millions of years. On the other hand, the era of machines and robots have just begun. In today's world these machines or the robots are like they need to be programmed before they follow instructions, but what if the machine started to learn on their own and this is where machine learning comes into a picture. Machine learning is the core of many futuristic technological advancements in our world. Today, you can see various examples or implementation of machine learning around us such as tesla's self-driving car Apple's Siri, Sophia AI robot and many more out there. So, the question that arises here is what exactly machine learning is. Machine learning is a subfield of artificial intelligence that focuses on the design of a system that can learn from and make decisions and predictions based on the experience which is data in the case of machines. Machine learning enables a computer to act and make data driven decisions rather than being explicitly programmed to carry out a certain task. These programs are designed to learn and improve over time when exposed to new data. One of the major sources confusions among the people around is that all three of them i.e., Artificial Intelligence (AI), Machine Learning (ML) and Deep Learning (DL) are same which is not the case (Figure 2.3).

AI is a broader concept of machines being able to carry out a task in a smarter way and it covers anything which enables the computer to behave like humans. Think of a famous Turing test to determine whether a computer can think like a human being or not, if you're talking to Siri on your phone and you get an answer, you're already very close to it and this is about artificial intelligence. Now coming to the machine learning part, it is a subset or the current application of AI. ML is based