# Intelligent Digital Monitoring of the Levels of Stress


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**Abstract** The human body is regulated by a variety of glands that produce hormones, which are responsible for making us feel good or bad. Cortisol is a hormone that falls under the category of feel-bad hormones as it increases stress levels in the body. Stress can come in different forms such as acute, episodic acute, and chronic and can have adverse effects on a person's physical, mental, and emotional health. It can lead to the development of diseases such as diabetes, heart ailments, depression, asthma, obesity, Alzheimer's disease, gastrointestinal problems, and anxiety, among others. Early diagnosis and prevention of such diseases can be aided by monitoring and predicting stress levels. Various techniques are reported in the literature to measure stress, including wearable devices, behavioural coding, self-reporting, physiological measuring tools, heart rate variability analysis, psychosocial approach, perceived stress scale, and measuring salivary and hair cortisol. This chapter focuses on digital monitoring techniques for measuring stress levels, such as using intelligent wireless sensor systems, personal digital assistants, mobile applications, bioelectronics, digital signal processing, and other such technologies. The role of recent computational techniques such as machine learning, deep learning, and the Internet of Things in real-time stress detection has also been discussed, highlighting potential directions for further research in this area.

**Keywords** Episodic acute stress · Chronic stress · Bioelectronics · Deep learning · Real-time stress detection

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## 1 Introduction

Human thought and behaviour are influenced by various factors, including stress management. Stress was originally defined by Hans Selye in 1936 as a non-specific response of the body to any demand [1]. Stress is a reaction of the body towards different situations and circumstances which the mind finds complex to process or handle. Multitasking can often become physically and mentally exhausting for the body's processes, inducing stress. The secretion of hormones by various glands regulates these bodily processes. Cortisol, a feel-bad hormone, is responsible for increasing stress levels in the body. This primary stress hormone releases glucose in the bloodstream and has various effects on different parts of the body. Health risks, bad habits, and diseases can further increase stress levels. Figure.1 displays some parameters that affect stress levels.

There are many types of stress such as acute stress, episodic acute stress, chronic stress, etc. which can affect a person's physical, mental, and emotional well-being. The types of stress are tabulated in Table 1. This can also induce illnesses and disorders leading to several diseases such as diabetes, heart ailments, depression, asthma, obesity, Alzheimer's disease, gastrointestinal problems, anxiety, etc. Stress has huge impact on the neurological processes as well as other physical and emotional processes of human body and is a game-changer in making or breaking a person. Therefore, the management of stress levels becomes a very important factor

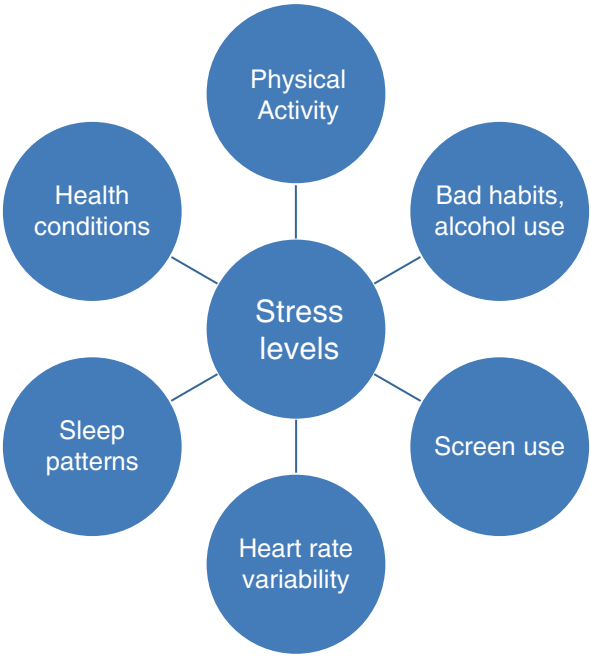


**Fig. 1** Parameters affecting stress levels

**Table 1** Types of stress

| Sr. No. | Types of stress | Characteristics |
|---|---|---|
| 1. | Acute stress | • Body's reaction towards a relatively new and challenging circumstance<br>• Severe acute stress could result from post-traumatic stress disorders<br>• Reactions towards life threatening situations can cause severe acute stress |
| 2. | Episodic acute stress | • Frequent episodes of acute stress cause this type of stress<br>• Anxiousness and worries in routine activities |
| 3. | Chronic stress | • When stress levels remain high for a significant period of time, chronic stress is induced in body<br>• Causes various disorders, headaches, changes in sleeping patterns, eating patterns, etc. |

for the overall well-being of a person. Onus lies on the research community to find out technological ways to measure the levels of stress in human body so that appropriate methods for stress management may be devised.

This chapter discusses various techniques that are reported in the literature to measure stress levels such as wearable devices, behavioural coding, self-reporting, physiological measuring tools, heart rate variability analysis, psychosocial approach, perceived stress scale, measuring salivary and hair cortisol, etc. [2].

This chapter also focuses on the techniques involving digital monitoring of stress levels, for example, using intelligent wireless sensor systems, personal digital assistants, mobile applications, bioelectronics, digital signal processing, etc. The role of recent computational techniques like machine learning, deep learning, and the Internet of Things in real-time stress detection has also been discussed.

## 2 Measurement of Stress Levels

Various physical, behavioural, situational, emotional, and psychological factors lead to the rise in levels of stress. Quantitative indication of stress by observation of these factors can help in the management of stress. For instance, human facial expressions can indicate the presence of stress. According to the facial action coding system developed by Ekman and Friesen, seven basic emotions anger, disgust, neutral, fear, happiness, sadness, and surprise are innate and universal to humans and these can be used for indication of stress levels. Digital techniques to measure stress levels are gaining popularity due to their non-invasive and convenient nature. In this section, we discuss various techniques which can help in the measurement of stress levels in the human body.

## 2.1 Wearable Devices

In the rapidly emerging field of stress monitoring, real-time cortisol-sensing wearable devices are being developed. Wearable cortisol aptasensors and cortisol sweat-sensing devices [3] significantly collect stress-related information which can be used for monitoring and measurement. Objective stress monitoring systems are also being designed which can measure stress based on electrocardiograms (ECG), photoplethysmography (PPG), and galvanic skin response. The wearable sensors used for the above-said technique are Shimmer3 ECG, Shimmer3 GSR+, and Empatica E4 [4].

Wearable devices which involve the audio signal and heart rate monitoring for stress detection provide effective solutions in a real-world scenario. Machine learning is applied to test the accuracy of these frameworks so that these can be employed in the real world for the safety of people especially children [5]. A list of currently available wearable devices which monitor stress and related parameters is given in Table 2.

The wearable devices provide lot of benefits but face several challenges as well. Accuracy of these devices needs further research elaboration. COVID-19 pandemic has brought a change in the lifestyle of people. More dependency on digital devices has added to the stress parameters in human body and also affects the overall well-being by introducing habitual changes.

Therefore, the use of wearable devices should be planned with care and consideration, while not affecting the very spirit of natural bodily processes. Figure.2 shows a graphical abstract of stress detection using wearable devices, where the data is collected by the wearable sensors [6]. The collected data is then pre-processed using various data cleaning approaches. From the data that is now put in format by

**Table 2** Wearable devices for stress monitoring

| Name of the device | Characteristics |
|---|---|
| Fitbit Sense2 | Scans the body for the presence of stress, notifies the user, asks for feedback, and provides suggestions on coping mechanisms |
| Garmin watch | Provides stress tracking by taking into consideration heart rate variability measurements and also monitors sleep, guides into breathing exercises |
| Samsung smartwatches | Heart rate monitoring, stress tracking, heart rate variability measurement, mindfulness, meditation, |
| Apple watch series 8 and watch SE | Third-party apple watch apps may provide stress monitoring features by taking into consideration the heart rate variability |
| Google Wear OS smartwatches | Heart rate monitoring, breathing exercises, monitoring stressful moments |
| Apollo neuro | Haptic technology for skin vibrations, various modes such as energy, wakeup, clear, focussed, sleep, and renew |
| Muse2 | Uses seven electroencephalogram sensors along the scalp, real-time brain activity measurement, calming exercises, monitoring body movements and breathing, heart rate rhythm tracks using the pulse oximeter |

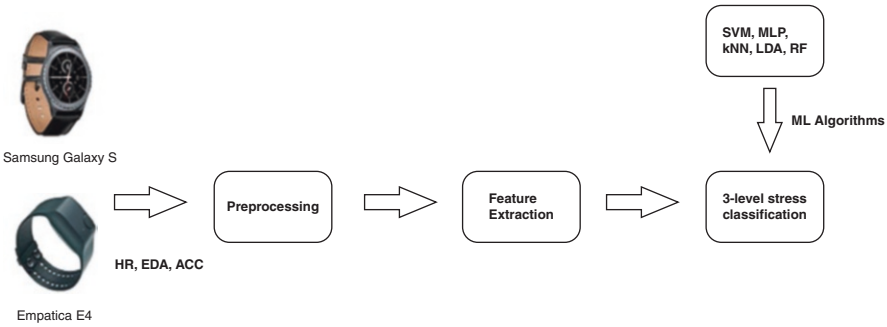


**Fig. 2** Graphical abstract of stress detection using wearables [6]

**Table 3** Various behaviours of stress management

| Stress management behaviours | |
|---|---|
| Positive behaviours | Deep breathing, exercising, mindfulness, yoga, listening to calming music, connecting with the community, finding time for yourself, walking, travelling |
| Negative behaviours | Alcohol use, smoking, addiction towards screens, absence of physical activities, junk eating |

pre-processing, relevant features are extracted. Then, classification techniques of machine learning are implemented to get 3-level stress classification.

## *2.2 Behavioural Coding*

The behavioural coding focusses towards the stereotypical behaviours of people under stress. The parental monitoring and psychological controls during adolescence years also affect the cognition and stress handling capabilities of the individual. The development of stereotypes during the early years affects thought and behaviour, which in turn affects the ways of managing stress by the body of that individual.

Electronic monitoring of the stress-inducing parameters plays a significant role in stress management. Intellectual physical disabilities also introduce stress levels at the unprecedented situations. The coding of all such behaviours under given circumstances is very important to design stress monitoring solutions for individuals with different backgrounds and abilities. Various stress management behaviours are listed in Table 3.

### 2.2.1 Self-Reporting

Self-reporting is a powerful tool for managing stress as it allows individuals to monitor their own stress levels and identify triggers for stress. Self-reporting involves tracking and recording one's thoughts, emotions, and behaviours over time to gain insights into patterns and trends. One of the primary benefits of self-reporting for stress management is that it empowers individuals to take control of their own well-being. By tracking their stress levels and identifying triggers, individuals can develop strategies to manage stress proactively. For example, if an individual notices that they feel particularly stressed after a certain activity or in response to a specific situation, they can take steps to avoid or minimize those triggers. Self-reporting can take many forms, including keeping a journal, using mobile apps, or participating in online support groups. Mobile apps, in particular, have become increasingly popular for self-reporting stress management. These apps often include features such as mood tracking, stress tracking, and goal setting, enabling individuals to monitor their progress and stay motivated.

While self-reporting is a powerful tool for stress management, it also has some limitations. Self-reported data may be subject to bias or inaccuracies, as individuals may not always accurately recall or report their emotions and behaviours. Additionally, self-reporting may not be sufficient for individuals with severe or chronic stress, as they may require more intensive interventions such as therapy or medication. Self-reporting can be an effective tool for managing stress, particularly for individuals with mild to moderate stress. By tracking and monitoring their stress levels, individuals can gain insights into their own well-being and develop strategies to manage stress proactively.

Self-reporting is a way of managing stress by being vocal about it. Listing the issues that cause stress helps in finding ways to alleviate these. Wearable sensors provide a personalized stress monitoring mechanism in order to measure self-reported stress. The ways of reporting include developing a mood adjective checklist, filling up questionnaires and surveys, getting yourself tested through remote applications via web browsers or mobile phone interface. During the stages of pregnancy, the hormonal changes introduce several mood related issues which can be monitored via self-reporting and stress can be categorised accordingly. This makes it possible to assess the risks during pregnancy through self-reported stress.

### 2.2.2 Physiological Measuring Tools

There are various studies to find out accurate algorithms to measure the stress levels of users. One such study is about inconspicuous stress monitoring system that makes use of physiological sensors [7]. In this system, around 50 participants were included in the experimentation through a mobile application interface. Three physiological signals were taken into consideration, viz. heart rate, galvanic skin response, and skin temperature, in order to classify the stress-related data and produce distributions. The algorithms of support vector machines and K

means-clustering were deployed to carry out the classification and monitoring tasks. This system gave an accuracy of about 91.26 and is able to assist people in alleviating their stress significantly.

Another study considering the wearable physiological sensors to monitor stress in the working environments was developed as an integrated system using biological markers [11]. ECG, EDA, and EEG parameters were used to identify the stress in humans and correlate the detected stress with cortisol levels of salivary glands. The statistical analysis was majorly carried out using support vector machine classification algorithm. This system was able to test human stress and carry out the quantification of the stress levels. The results obtained from this study are further encouraging the design of portable and remotely controlled systems.

### 2.2.3 Heart Rate Variability Analysis

Heart rate variability (HRV) analysis is a technique that refers to the beat-to-beat fluctuations of the rate of heart [8]. The various factors that affect the heart rate are further instrumental in causing a rise in the stress levels. Therefore, the analysis of heart rate variability becomes paramount. There is various software which are capable to do this analysis. One such software is Kubios HRV [9] which is considered an advanced and easy-to-use software for HRV analysis. There are various data formats which can be supported by this software to process ECG and beat-to-beat data. The algorithm used in this software is QRS detection algorithm, and there are number of tools for analysis sample selection, trend removal, and artefact correction in order to complete the analysis task. The software can compute the time domain as well as frequency domain parameters of HRV and many other non-linear parameters as well. Various settings are there which are adjustable and optimum for different types of data. The results are available in different formats so that further processing can be done on different platforms and software. Heart rate variability analysis can be performed using HRV analysis software [10] which is available for Windows and MAC operating systems. It is ideal for human as well as animal cardiovascular studies. It displays the time domain, frequency domain as well nonlinear parameters associated with beat-to-beat analysis. HRV software utilizes algorithms and mathematical calculations to process and analyse heart rate data obtained from wearable devices, such as heart rate monitors or electrocardiogram (ECG) devices. These software applications can transform the raw heart rate data into meaningful metrics and provide comprehensive reports for further analysis.

HRV software can receive heart rate data from various sources, including wearable devices, fitness trackers, ECG monitors, or data files stored in compatible formats. The software may include data pre-processing capabilities to clean and filter the heart rate data, removing any artefacts or outliers that may interfere with accurate HRV analysis. It applies mathematical algorithms, such as time domain, frequency domain, and non-linear analysis methods, to extract relevant HRV metrics. These metrics include measures of overall HRV, sympathetic and parasympathetic activity, stress levels, and cardiovascular health markers. This software generates

detailed reports and visualizations, presenting HRV metrics in an understandable format. This enables users to track their HRV trends over time and identify patterns or changes in their autonomic function. It may also integrate with other health and fitness platforms, allowing users to synchronize and analyse their HRV data alongside other health parameters, such as physical activity, sleep patterns, and nutrition.

### 2.2.4 Psychosocial Approach

Psychosocial stress occurs when the individual is fearful of the social threats and situations such as feeling excluded from the society, fearing failures, fearing being evaluated by the society as per the set parameters. People having certain disorders like inflammatory bowel diseases, bipolar disorders, metabolic syndromes, etc. also encounter such challenges due to their health conditions. It is even observed that people with severe ailments such as cancer are being affected by the psychosocial stress with their weakening immune systems. Therefore, an approach to analyse this kind of stress and develop ways to manage it is the need of the hour.

One approach to monitor acute stress after a traumatic experience has been developed, which basically integrates the available evidence for behaviour therapy of cognition and recently found neuroscience results [11]. This approach signifies the importance of fear reduction learning which can be increased by modulation of glutamatergic systems, which are the major excitatory neurotransmitter systems in the nervous system. The integration of neurological findings with the digital technologies can be further explored in order to develop psychosocial approaches to monitor stress levels.

### 2.2.5 Perceived Stress Scale

Perceived stress scale is a psychological instrument which is helpful in finding out the perception of stress. It measures the degree which tells about the situations and circumstances that make the life of a person stressful. A study on the review of perceived stress scale was conducted, and it was found that reliability of internal consistency, factorial validity, and hypothesis validity of the perceived stress scale (PSS) was reported significantly by various research articles [12]. Questionnaires were quite helpful to measure the PSS and identify the stressful situations. However, there is a lack of computational methods to measure PSS and correlate it with other parameters which induce stress. Based on perceived stress scale tests, brain wave stress patterns can be generated and analysed. Various region-specific studies on PSS have also been made in Greece, Turkey, Spain, Germany, etc.

### 2.2.6 Measuring Salivary and Hair Cortisol

In today's world, the effects of stress on human health and overall well-being are well recognized. Therefore, establishment of biomarkers to measure the levels of stress over a period of time is critically required [13]. Saliva, urine, and hair cortisol are some of the hormones which can complement the real-time monitoring of stress levels. Hair cortisol as a parameter to assess stress is being used widely in the clinical studies. There are many studies which are focussing on these parameters individually, but there is a scope of exploring digital solutions which assess the levels of stress based on all of these three parameters to have a comprehensive analysis.

A smartphone-based technique has been developed to measure psychological stress based on salivary cortisol [14]. This technique involved the development of a mobile application which will measure the different concentrations of cortisol using images. The statistical analysis is then carried out and validation is done with the smartphone by using actual human saliva to evaluate the system.

### 2.2.7 Pupil Dilation Measurement

Pupil dilation measurement is a non-invasive digital technique used to measure stress levels. The size of the pupil changes as a result of the activity of the autonomic nervous system, which is responsible for the body's response to stress. The sympathetic nervous system activates the "Figureht or flight" response, causing the pupils to dilate, while the parasympathetic nervous system activates the "rest and digest" response, causing the pupils to constrict.

By measuring changes in the size of the pupils, researchers can infer the activity of the autonomic nervous system and estimate stress levels. Pupil dilation measurement can be done using a digital pupillometer, which is a small device that shines a light into the eye and measures the amount of light that is reflected back. The device can provide objective and accurate measurements of pupil size, which can be used to assess stress levels in various contexts, such as during cognitive tasks, emotional situations, or physical activity. However, it is important to note that other factors, such as lighting conditions, medication use, and individual differences, can also affect pupil size, so results should be interpreted with caution and in combination with other measures of stress.

### 2.2.8 Electroencephalography

EEG (electroencephalography) is a non-invasive technique used to record and measure the electrical activity of the brain. EEG can be used to measure stress levels by detecting changes in brainwave patterns that are associated with stress. When a person is under stress, there is an increase in the beta wave frequency in the frontal region of the brain and a decrease in the alpha wave frequency in the parietal and occipital regions of the brain.

In studies, participants who underwent stress-inducing tasks showed an increase in beta waves, particularly in the frontal area, and a decrease in alpha waves in the parietal and occipital regions. These changes in the brainwave pattern can be detected and analysed using EEG to indicate the level of stress.

Moreover, EEG can also be used to identify different stages of stress. For example, when a person is initially exposed to a stressful situation, there is an increase in the beta wave frequency in the frontal region. As the stress continues, the alpha wave frequency in the parietal and occipital regions also decreases. By analysing these changes in brainwave patterns, it is possible to differentiate between different stages of stress and provide early intervention. However, it is important to note that EEG is not a standalone method for measuring stress levels, and it should be used in combination with other techniques such as self-report questionnaires or behavioural observations.

Additionally, EEG requires specialized equipment and trained professionals to perform the analysis and interpretation of the results, which can make it more challenging to implement on a large scale.

### 2.2.9 Speech Analysis

Speech analysis is another digital technique used to detect stress levels. Stress affects the way we speak, altering the pitch, tone, and rhythm of our speech. Therefore, speech analysis can be a non-invasive, low-cost, and easy-to-use technique for detecting stress.

Several studies have investigated the use of speech analysis for stress detection. For example, researchers have used various features of speech, such as pitch, energy, and speech rate, to develop stress detection models. These models have been trained on speech samples collected from individuals under various stress conditions, such as public speaking, mental arithmetic, and cognitive tasks.

One study used automatic speech recognition (ASR) technology to transcribe speech and extract features such as the fundamental frequency (F0), spectral centroid, and formant frequencies. The study showed that speech features could be used to detect stress with an accuracy of up to 80%. Another study focused on the analysis of speech prosody, which includes features such as pitch, loudness, and rhythm. The study found that speech prosody can be used to detect stress with an accuracy of up to 85%.

Overall, speech analysis can be a promising digital technique for detecting stress levels. However, the accuracy of the technique depends on various factors, such as the quality of the speech signal, the type of stressor, and the individual differences in speech patterns. Further research is needed to develop reliable and accurate stress detection models based on speech analysis.

### 2.2.10 Computer Mouse Usage

Computer mouse usage can be used as a proxy for stress detection. When a person experiences stress, their movements can become more erratic and jittery, which can be reflected in the patterns of mouse movement. This has led to the development of software applications that can track mouse movements and use them as a means of detecting stress. These applications typically use machine learning algorithms to analyse the patterns of mouse movement and identify when they deviate significantly from the user's normal behaviour. However, it's important to note that mouse movement is just one potential indicator of stress and should be used in conjunction with other measures for more accurate results.

## 3 Digital Monitoring of Stress Levels

The digital monitoring of stress levels includes the use of intelligent wireless sensor systems, personal digital assistants, mobile applications, bioelectronics, digital signal processing, machine learning, etc. This section discusses such techniques which would be helpful in monitoring the stress levels efficiently.

### *3.1 Intelligent Wireless Sensor Systems*

Intelligent Wireless Sensor Systems (IWSS) can be used for stress monitoring in a variety of applications, including healthcare, sports, and workplace safety. These systems use advanced sensors to detect and monitor physiological signals associated with stress, such as heart rate variability, electrodermal activity, and respiration rate.

The data collected by these sensors can be transmitted wirelessly to a central monitoring system, where it can be analysed and used to identify patterns of stress and potential triggers. This information can be used to help individuals manage their stress levels, as well as to inform organizational policies and interventions aimed at reducing workplace stress.

In addition to physiological sensors, IWSS can also incorporate other types of sensors, such as environmental sensors, to provide a more comprehensive understanding of the factors contributing to stress. For example, temperature, noise, and lighting can all have an impact on stress levels, and incorporating these data into IWSS can help identify potential stressors and inform interventions aimed at reducing them.

IWSS have the potential to revolutionize stress monitoring by providing real-time, objective data that can be used to inform personalized interventions aimed at improving mental health and well-being. Wireless sensor systems make use of sensing devices to carry out the task at hand. Various smartwatches and fitness trackers

which monitor the daily routine and bodily processes of individuals are proving to be quite effective in monitoring the levels of stress during different intervals of time. Salivary sensors and sweat cortisol sensors are becoming the front runners in measuring the stress levels effectively.

A device named SKINTRONICS [13] has been created to determine the stress levels by using electrodermal sensing of skin galvanic response. Personal health monitors using wireless intelligent sensor systems are being developed to monitor a group of people and identify their stress levels [15]. In order to accomplish these tasks, high precision computational instrumentation is required.

### *3.2 Personal Digital Assistance*

Personal digital assistants are a way of breaking the barriers of social stigma to report, analyse and monitor personal health issues. A non-intrusive stress monitoring system has been developed based on the personal digital assistants. Sensing and estimation of stress is done in two phases in this system. The sensing phase consists of measurement of heart rate, skin temperature variation, and electrodermal activities. All these parameters are acquired from the finger without causing any comfort issue to the individual [16]. The benefits of personal digital assistants in healthcare domain are multi-fold, therefore steps are being taken to make use of these for stress monitoring.

### *3.3 Mobile Applications*

Mobile applications pave the way to make digital assistance convenient and friendly for the users. The following Table 4 lists some of the mobile applications which are helpful in stress management.

### *3.4 Bioelectronics and Digital Signal Processing*

For continuous stress monitoring over a period of time, wearable bioelectronics are quite significant. Emotion recognition systems based on non-intrusive and intrusive sensors have been developed [18]. There are three stages in this system: setting up experiments for physiological sensing, feature extraction using pre-processing of signals, and recognition using learning-based system. Four signals are monitored and analysed to find out the stages of stress. These signals are blood volume pulse, pupil diameter, skin temperature, and galvanic skin response. Support vector machines are used to classify the states of stress and provide information about the emotional changes in the person.

**Table 4** Mobile applications for stress management [17]

| Sr. No. | Name | Features |
|---|---|---|
| 1 | Breathe2Relax | Breathing exercises and instructions, documentation on stress management, information on the harmful effects of stress |
| 2 | Pacifia | Deep breathing and muscle relaxation guided exercises, anti-anxiety experiments, mood tracking, analysis of thinking patterns, and anxiety triggers |
| 3 | GPS for the soul | Stress level identification, meditation tools, calming pictures, and music |
| 4 | Happify | Brain training, activities to get rid of stress, anxiety, and negativity |
| 5 | Stress doctor | Stress busting deep breathing exercises, heart rate monitoring, etc. |
| 6 | Headspace | Guided meditation sessions, mindfulness training |
| 7 | Personal Zen | Games based on clinical findings, reducing anxiety levels |
| 8 | My mood tracker | Helping you to feel good and manage your moods |
| 9 | Squeeze and shake | Anger management |
| 10 | Pocket yoga | Yoga techniques for relaxation, range of yoga styles from beginner to difficulty level |
| 11 | Finding optimism | Recording symptoms and triggers, data visualization tools, information on wellness strategies |
| 12 | The Mindfulness app | Guided meditation, calming music, natural sounds |
| 13 | Pay it forward | Stress reduction with kindness, connecting with the community |

## *3.5 Cognitive Behavioural Therapy and Conversational Chatbots*

Cognitive behavioural therapy (CBT) is a technique of assessing human thought and behaviour to manage the problems faced by an individual. It has proven to treat acute stress disorders by monitoring and managing anxiety levels and stress reactions. If acute stress disorder is not treated timely, it may lead to severe post-traumatic stress disorders (PTSD). Since, CBT is a talk therapy, it makes it difficult for people with social issues to connect with their medical health counsellor. Therefore, techniques are being evolved to prepare chatbots who can counsel the subjects using cognitive behavioural therapy techniques. Connecting with a chatbot is much convenient for such people as they no longer have the fear of being judged while discussing about their mental health issues. The terminology used for such chatbots is therapy chatbots, which aim to have conversations with the patient in order to help them with anger, anxiety, and depression issues.

Table 5 provides a list of some chatbots which are helping people in managing stress.

**Table 5** Chatbots for stress management [19]

| Sr. No. | Name | Features |
|---|---|---|
| 1 | Woebot | Mood monitoring, cognitive behavioural therapy, therapeutic conversations |
| 2 | Moodkits | Depression monitoring, cognitive behavioural therapy, activity tools |
| 3 | MoodNotes | Categorizes user's thought patterns, records their emotions, identify thinking errors |
| 4 | Wysa | AI based, emotionally intelligent chatbot, dialectical behaviour therapy, guided meditation, evidence-based CBT |
| 5 | Youper | Monitors and improves emotional health, personalized conversations, mindfulness techniques |

## 4 Role of Recent Technological Trends in Real-Time Stress Detection

Real-time stress detection involves the collection of data in real time using various sensors and then sending it to a processing unit through some mobile interface. The processed information is relayed back to the user to detect the levels of stress at the given time. The processing unit capable to carry out this task has a number of technologies running in its background such as database systems, machine learning, deep learning, and Internet of Things. This section discusses the role of such recent computational techniques employed for detection of stress in real time.

### *4.1 Machine Learning*

Machine learning (ML) has a significant role to play in stress detection and monitoring. ML algorithms can analyse large volumes of physiological and environmental data collected by sensors to identify patterns and predict future stress events [20]. Here are some ways in which ML can be used for stress detection and monitoring:

- Feature extraction: Machine learning algorithms can automatically identify relevant features from physiological signals, such as heart rate variability, electrodermal activity, and respiration rate, that are associated with stress. These features can then be used as inputs to predict stress levels.
- Pattern recognition: ML can be used to identify patterns in physiological and environmental data that are associated with stress, such as changes in heart rate, respiration rate, and skin conductance. This can help in the early detection of stress and provide an opportunity for timely interventions.
- Personalization: ML algorithms can be trained on individual data to develop personalized stress models. This can help in providing tailored interventions and support to individuals, based on their unique stress patterns.
- Predictive analytics: ML can be used to develop predictive models that can identify individuals who are at risk of developing stress, based on their past stress

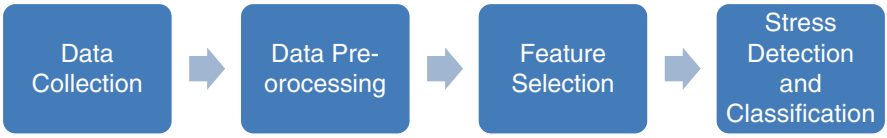


**Fig. 3** Process of stress detection using machine learning

patterns, environmental factors, and other relevant data. This can help in preventing stress-related illnesses and promoting early interventions.

- Real-time monitoring: ML can be used to develop real-time stress monitoring systems that can provide continuous monitoring of physiological and environmental signals. This can enable timely interventions and support for individuals who are experiencing high levels of stress.

Machine learning has the potential to revolutionize stress detection and monitoring by providing real-time objective data that can be used to inform personalized interventions aimed at improving mental health and well-being. ML-based stress detection and monitoring systems can be used in a variety of settings, such as healthcare, sports, and workplace safety, to help individuals and organizations manage stress and promote well-being. The general process of using machine learning to detect and classify stress levels is shown in Fig. 3.

For instance, if we are developing a system that uses social media analysis to identify stress. One method would be to collect the social media posts pertaining to the user by using various data collection methods. Next step would require the cleaning and pre-processing of the data. The dataset is organized in a way so that feature selection could be possible. And after that the machine learning model is trained and accordingly the results for stress detection and classification are generated [21].

## *4.2 Deep Learning*

Deep learning (DL) has emerged as a powerful tool for stress detection and monitoring. DL algorithms can learn complex representations of physiological and environmental data, which can be used to accurately predict stress levels and identify potential triggers. Here are some ways in which DL can be used for stress detection and monitoring:

- Multimodal data integration: DL algorithms can integrate data from multiple sensors, including physiological sensors (such as heart rate variability, electrodermal activity, and respiration rate) and environmental sensors (such as temperature, noise, and lighting), to develop a more comprehensive understanding of the factors contributing to stress.

- Transfer learning: DL algorithms can use pre-trained models to extract features from physiological and environmental signals that are relevant to stress. This can help in developing more accurate stress models, even when data is limited.
- Real-time monitoring: DL can be used to develop real-time stress monitoring systems that can provide continuous monitoring of physiological and environmental signals. This can enable timely interventions and support for individuals who are experiencing high levels of stress.
- Personalization: DL can be used to develop personalized stress models, based on individual data. This can help in providing tailored interventions and support to individuals, based on their unique stress patterns.
- Deep reinforcement learning: DL algorithms can be used to develop adaptive stress interventions, based on real-time stress monitoring. This can enable personalized interventions that are tailored to an individual's unique stress patterns.

Deep learning has the potential to revolutionize stress detection and monitoring by providing real-time, objective data that can be used to inform personalized interventions aimed at improving mental health and well-being. DL-based stress detection and monitoring systems can be used in a variety of settings, such as healthcare, sports, and workplace safety, to help individuals and organizations manage stress and promote well-being. Machine learning techniques require hand-crafted manually generated features in order to detect stress. This drawback can be eliminated by the use of deep convolutional neural networks. One such architecture has been proposed by researchers where all the parameters obtained from different sensors are processed individually in different 1D convolutional blocks [22]. These different set of features are then concatenated and processed further using deep learning models. Deep learning models are proving to provide much better accuracy by use of deep neural networks and address the issue of manual feature generation.

### *4.3 Internet of Things*

Internet of Things paradigm provides opportunities to manage and monitor stress levels by making use of sensors and transmitting that information directly to the processing units. Real-time stress monitoring can be done using Internet of Things concepts. The parameters like heart rate, blood pressure, and body temperature are captured using sensors. The collected information is then pre-processed and sent to the processing units or devices through the internet, and the real-time results can be displayed or visualized using high end monitoring systems [23].

A cloud server and Internet of Things based stress monitoring assistance system has been proposed recently, which aims to detect stress in real time [23]. This system has the capability to provide personal assistance to people in stress. Galvanic skin response is taken as the input parameter to measure stress by the stress device. The threshold value is identified after due analysis on MATLAB software and then the interfacing of the stress device with the cloud server is done to log real data.

Following are some more ways in which IoT can be used for stress detection and monitoring:

- Wearable devices: IoT-enabled wearable devices, such as smartwatches and fitness trackers, can collect physiological data (such as heart rate and skin conductance) and environmental data (such as temperature and noise) to provide a comprehensive understanding of an individual's stress levels.
- Smart home devices: IoT-enabled smart home devices, such as smart thermostats and lighting systems, can collect data on environmental factors that can impact stress levels, such as temperature and lighting. This can provide a more comprehensive understanding of the factors contributing to stress.
- Real-time monitoring: IoT-enabled devices can collect and transmit data in real time, allowing for continuous monitoring of physiological and environmental signals. This can enable timely interventions and support for individuals who are experiencing high levels of stress.
- Data analytics: IoT can be used to collect and analyse large volumes of data, which can be used to develop predictive models and identify patterns that are associated with stress. This can help in the early detection of stress and provide an opportunity for timely interventions.
- Personalization: IoT can be used to develop personalized stress models, based on individual data. This can help in providing tailored interventions and support to individuals, based on their unique stress patterns.

IoT-based stress detection and monitoring systems can be used in a variety of settings, such as healthcare, sports, and workplace safety, to help individuals and organizations manage stress and promote well-being [24].

## *4.4 Brain-Inspired Computing*

Brain-inspired computing, also known as neuromorphic computing, is an emerging field that draws inspiration from the structure and function of the human brain to design computing systems. This technology has the potential to revolutionize stress detection by leveraging the power of artificial neural networks to process large amounts of data in real time. One of the primary advantages of brain-inspired computing is its ability to process data in a parallel, distributed manner, similar to the way in which the human brain processes information. This allows for the efficient processing of large amounts of data, making it well-suited for stress detection and monitoring applications.

Brain-inspired computing can be used to detect stress by analysing physiological signals such as heart rate variability, electroencephalography (EEG) signals, and skin conductance. By modelling the way in which the human brain processes these signals, artificial neural networks can be trained to detect patterns and identify signs of stress. Brain-inspired computing can also be used to develop personalized stress detection models based on individual data. By training the neural networks on

individual physiological and environmental data, the models can be tailored to each individual's unique stress patterns, allowing for more accurate and effective stress detection.

However, the use of brain-inspired computing for stress detection also poses some challenges. One of the significant challenges is the need for large amounts of data to train the neural networks effectively. Additionally, the interpretability of the models can be challenging, making it difficult to understand the factors that contribute to stress. Overall, brain-inspired computing holds significant promise for stress detection and monitoring, offering a powerful tool for processing and analysing large amounts of data in real time. Further research in this area has the potential to lead to the development of more accurate and effective stress detection models, enabling individuals to take timely action to manage stress and improve their overall well-being.

## *4.5 Natural Language Processing*

Natural Language Processing (NLP) is a subfield of artificial intelligence that focuses on the interaction between computers and human language. NLP has the potential to revolutionize stress detection and monitoring by analysing textual data such as social media posts, chat messages, and emails to detect patterns and identify signs of stress. One of the primary advantages of NLP is its ability to analyse unstructured data, enabling the detection of stress in natural language expressions. By analysing linguistic features such as sentiment, tone, and lexical patterns, NLP algorithms can detect stress and other emotional states in text.

NLP can also be used to monitor stress over time, enabling the detection of patterns and changes in stress levels. By analysing longitudinal data, NLP algorithms can identify stress triggers, monitor the effectiveness of stress management interventions, and provide personalized recommendations for stress management. However, the use of NLP for stress detection and monitoring also poses some challenges. One of the significant challenges is the need for large amounts of data to train the NLP models effectively. Additionally, NLP algorithms may have difficulty understanding sarcasm, irony, and other nuances of language that can affect the interpretation of emotional states.

NLP holds significant promise for stress detection and monitoring, offering a powerful tool for analysing natural language expressions to identify signs of stress. Further research in this area has the potential to lead to the development of more accurate and effective NLP models, enabling individuals to take timely action to manage stress and improve their overall well-being.

## 5 Conclusions and Future Research Directions

This chapter offers a comprehensive overview of digital monitoring and detection techniques that can be effectively utilized for stress management. The recent advancements in digital technologies, such as the Internet of Things, machine learning, deep learning, and brain-inspired computing, have led to a surge in studies exploring these techniques for real-time stress detection. However, despite these technological advancements, there are numerous challenges that must be addressed. Firstly, the presence of a digital divide can create barriers in effectively utilizing these digital techniques. Secondly, testing and validating these techniques to establish their accuracy in various scenarios are significant challenges. Additionally, it is essential to consider the unique circumstances and situations of individuals experiencing stress, which can significantly complicate the problem. Thus, a comprehensive analysis of all parameters affecting stress levels is necessary to establish correlations and develop integrated digital solutions. This chapter not only discusses various digital techniques of stress monitoring but also presents a literature review in this area, shedding light on potential avenues for future research. There are several potential future research directions that could be explored to improve stress detection and monitoring techniques. Some of these include the following:

- Developing digital tools that can overcome the digital divide: One of the primary challenges in utilizing digital techniques for stress monitoring is the presence of a digital divide. Future research could explore ways to bridge this divide and develop digital tools that are accessible and user-friendly for all individuals, regardless of their technological expertise.
- Exploring the use of augmented reality and virtual reality: Augmented reality (AR) and virtual reality (VR) technologies could offer innovative ways to monitor stress levels in real time. For example, AR or VR environments could simulate stress-inducing situations, allowing individuals to practice stress management techniques in a controlled setting.
- Utilizing wearable technology for stress monitoring: Wearable technology, such as smartwatches and fitness trackers, could offer a non-invasive way to monitor stress levels in real time. Future research could explore ways to improve the accuracy of wearable sensors and integrate them with other digital tools for more comprehensive stress monitoring.
- Examining the role of social media in stress monitoring: Social media platforms have become increasingly popular for individuals to express their emotions and share their experiences. Future research could explore ways to utilize social media data for stress monitoring, such as analysing language patterns and sentiment analysis.
- Developing personalized stress management solutions: As mentioned in the paragraph, it is essential to consider the unique circumstances and situations of individuals experiencing stress. Future research could explore ways to develop personalized stress management solutions that are tailored to an individual's specific needs and circumstances. This could involve combining multiple digital

techniques, such as machine learning and brain-inspired computing, to develop comprehensive solutions.

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