Smart-Pillow: An IoT based Device for Stress Detection Considering Sleeping Habits

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***Abstract*—The quality of sleep during the night reflects on productivity during the day. To make the most out of a day, it is important to understanding the factors such as stress which impair sleep. Advances in technologies may aid a person to self-analyze such situations. For this, we propose a system which helps in stressfulness of a person based on sleeping habits. Physiological parameters such as temperature, blood pressure, respiration rate, and heart rate tend to vary during the NREM (Non Rapid Eye Movement) and REM (Rapid Eye Movement) stages of sleep. Non-physiological parameters such as the number of sleeping hours, the range of snoring, the sleeping position, and environmental conditions can also affect the quality of sleep. These factors are considered here in order to analyze sleeping habits. A system is defined which can predict stress levels up to five states: High, Medium-High, Medium, Medium-Low and Low stress.**

***Index terms*—** Internet of Things (IoT), Smart Healthcare, Smart Living, Smart Home, Stress Sleep, Stress Detection, Sleeping Habit

I. Introduction and Novel Contributions

Stress can be defined as a state of mental or emotional strain due to unavoidable or demanding circumstances. Stressors could be anxiety, improper food consumption, work tensions, family problems, lack of sleep etc. [1]. In this work, the dependency of the quality of sleep on stress variations is considered. The process of sleeping is classified into five stages: Stage 1, 2, 3, 4 and REM (Rapid Eye Movement). Stages 1 through 4 are considered to be NREM (Non Rapid Eye Movement) stages. Stages 1 and 2 are considered as light sleep stages.Stages 3 and 4 are considered as deep sleep stages. REM state is characterized by rapid eye movement even with the eyes closed, with intense brain activity and vivid dreams. Changes in the body temperature, heart rate and blood pressure, which affect stress levels during the day, are observed throughout the different stages of sleep [2].

Physiologically, sleep may be described as the antithesis of stress. The hormone *cortisol* is suppressed in our body during the early phases of sleep [3]. On the other hand, stress activates the biological pathway called the hypothalamic-pituitary-adrenal (HPA) axis that promotes the production of cortisol [3]. Activity in the HPA axis increases prior to waking up, marking the end of sleep [2]. The interrelation between stress and sleep is reflected by the fact that the sleep cycle is closely regulated by the HPA pathway, a primary player in body's stress-response. The immune system, which defends our body against diseases, is another key player in the relationship between stress and sleep. Two signaling molecules that orchestrate the functions of the immune system, viz. interleukin 1 beta and tumor necrosis factor, have been shown to regulate sleep. In rabbits, NREM sleep has been found to increase when they are injected with interleukin 1 beta or tumor necrosis factor [4]. Sleep is interrupted in the absence of these molecules [4]. Social stress in mice has been linked with the enhanced production of interleukin 1 beta and tumor necrosis factor [5].

The schematic representation of the idea presented in this research is shown in Fig. 1. The core of this work is to help individuals track their sleep and be alerted to potential incidence of stress based on their own sleeping patterns.

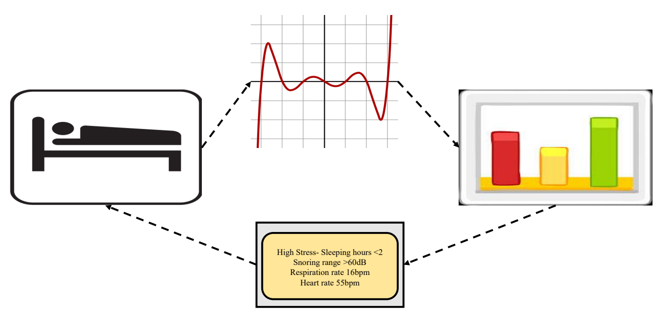

Fig. 1: Schematic Representation of Smart-Pillow.

Advances in technology and science may help people to assess changes in their own behavior, induced by stress in daily life. Sleeping disorder is a primary stressor, along with other factors, such as emotional imbalance and eating disorders [2], [6]. 50-70 million US adults face sleep disorders and try to normalize their sleep behavior by regulating sleep duration and adjusting schedules; however, changing habits is difficult [7]. Instead of resorting to longer and more tedious methods to maintain a record of their sleeping patterns to improve it, it would be better to recognize the underlying cause of stress that may be affecting sleep. Sleep has been studied by itself as a process involving changes in physiological parameters. However, the relationship between stress and sleeping behavior remain unexplored [8], [9]. In this paper, we propose a device which allows users to detect and potentially control stress based on their own sleeping habits. This research proposes the idea of a Smart-Pillow connected to a wireless tracker as a device to help monitor sleeping habits.

The **novel contributions of this paper** are the following:

- A continuously monitoring device which gets activated only when a person is lying on bed.
- A non-invasive technique which allows the person to analyze behavior considering sleeping habits.
- Determining the stress state of a person based on the sleeping pattern throughout the night.
- Providing diagnostic results and home remedies in order to maintain or control the stress variations based on their characteristics for future improvement.
- Allowing the user to detect the exact level of stress variation by classifying stress states into five levels based on their sleeping habits.

By detecting sleeplessness and underlying stress, this study can be a significant advancement in the field of smart health care. A device prototype is presented in Fig. 2.

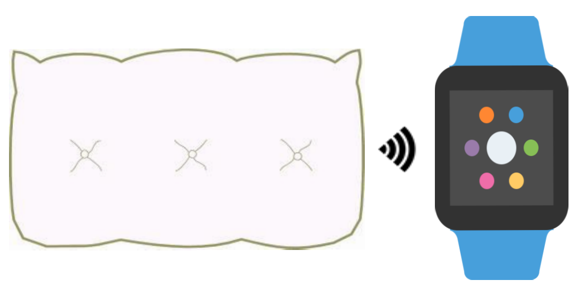

Fig. 2: Device Prototype of Smart-Pillow.

The rest of the paper is organized as follows: Section II provides a broad perspective of the system. Section III surveys the state of the art in related prior research. Section IV provides system-level modeling and feature extraction of the system. Section V presents the experimental implementation of the concept and the validation of results, and Section VI concludes the paper and presents possible future research.

II. Smart-Pillow: A broad perspective of Stress Management considering sleeping habits using IoT

An overview of the idea is presented in Fig. 3. As soon as there is a person lying on a pillow, the sensor available in the pillow gets activated first. This also activates the rest of the sensors available in the tracker attached to the hand of the person. This helps in continuous monitoring as long as the person is sleeping, and deactivates when there is no pillow pressure, thereby improving battery life. The sensor inputs are taken and sent to a database, where the processing is done. The final output along with the suggested remedies are represented on the display.

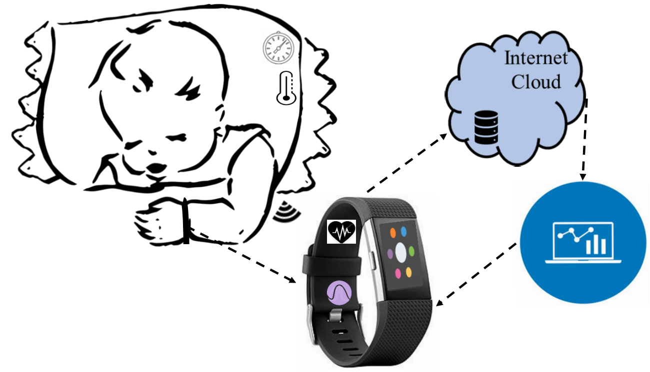

Fig. 3: Broad Conceptual View of Smart-Pillow.

III. Related Prior Research

There have been studies showing that quality of life is directly affected by sleep [6]. Disturbed sleep has been associated with increased instances of sickness, burnout syndrome, persistent psychophysiological insomnia and higher risk of occupational accidents [3]. 30 percent of the people experiencing higher work strain [3]. High work strain is defined here as having a demanding job in a position of low influence. Intrapersonal distress (experiencing anguish in ones mind) and self-reported feeling of loneliness have been linked to lower sleeping efficiency and poor sleep quality [10]. Disturbed sleep has been recorded in a mouse model of chronic mild stress, and the effect of stress on sleep in this case was rescued by acting on certain biological pathways relevant to stress [11]. A study of sleep patterns involving participants and already existing wearables is given in [12]. However, the study did not investigate the relationship between stress and sleep. Without using wearables, a mobile application has been developed in [13] but the relationship with stress variations during the day was not studied here. Out of many available wearables and non-wearables present, a few of the most commonly used devices are given in Table I. The Fitbit activity trackers are wristwatches which automatically track sleep and sleep stages solely through heart rate monitoring [14]. SleepScore Max, a non-wearable device, which allows the users to understand their sleeping patterns, does not provide suggestions on stress management [15]. Also, a connection to IoT enabling access of the information in the future was not explored in this. The wearable band Xiaomi Mi tracks sleep patterns using the pulse of a person [16]. However, the relationship between stress and sleep is not mentioned here. Eversleep is a wearable which assists users to have a peaceful sleep by monitoring their breathing patterns and helping them control their snoring behavior [17]. However, only one physiological parameter, viz. the respiration rate, is considered here. Moreover, the relationship between stress and sleep has not been mentioned here. A non-wearable which wraps around the mattress is provided by Beddit [18]. However, this only recognizes and helps in managing the snoring sound and also does not study the relationship with stress. Eight is another mattress wrapper sleep tracker that is available [19]. This tracks parameters such as temperature, breathing rate, humidity, heart rate and light levels, but does not assess the relationship between the tracked parameters and stress variations. Dreem is a head band wearable which helps a person to fall asleep by simulating slow brain waves [20]. However, this does not consider various other physiological parameters that vary during sleep and does not address the relationship between stress and sleep.

TABLE I: Sleep Trackers

Name	Approach	Features	Drawback
Fitbit [14]	Wearable	Heart rate monitor, sleep stages monitor	Does not manage stress with sleep.
SleepScore Max [15]	Non-wearable	Invisible radio wave sleep tracking	Does not manage stress with sleep.
Nokia Sleep [21]	Non-wearable	Uses Ballistocardiography sensor	Does not manage stress with sleep.
Xiaomi Mi Band 3 [16]	Wearable	Pulse Monitor	Does not manage stress with sleep.
Eversleep [17]	wearable	Snoring and breathing interruptions	Does not manage stress with sleep.
Beddit [18]	Non-wearable	Monitors snoring	Does not manage stress with sleep.
Eight [19]	Non-Wearable	Humidity, temperature, heartbeat, breathing rate	Does not manage stress with sleep.
Dreem [20]	Wearable	Simulates slow brain waves	Does not manage stress with sleep.

It is evident that the state of art today does not address the relationship between stress variations during the day and sleeping behaviors at night. This research provides a device prototype which can establish such a relationship between stress and sleeping habits.

IV. System level modeling of Sleep Monitoring System

Whenever there is a person sleeping or lying on the pillow, the sensor station in the pillow triggers the sensor station on the tracker. As soon as there is no person sleeping on the pillow, the tracker stops, thereby improving battery life. When there is an activation in the sensor station in the pillow and the tracker, the following factors are considered and are later sent to a database for storage:

- Number of hours of sleep
- Snoring sound range
- Respiratory rate range
- Heart rate range

Several studies have documented the effects of stress on various measurable physiological indicators of sleep, and on mental faculties important for day-to-day activities. Polysomnography, a technique used to identify the various stages of sleep, consists of electroencephalography which detects brain waves, electroculography which detects eye movements and electromyography, which records muscle tone. Studies based on polysomnography have observed that an anticipation of increased demand (worrying about impending/expected work)may disrupt some physiological indicators of sleep, viz. a decrease in the period of slow wave sleep and an increase in the heart rate [22]. Slow wave sleep is the deepest phase of non-rapid eye movement sleep, during which somnambulance (sleep walking), dreaming and memory consolidation occur [23]. Total sleep time and degree of sleep fragmentation (episodes of interrupted sleep) have been linked to poorer performance in psychomotor tests, which record the ability of the participants to engage in motor responses, and in cognitive tests which assess mental capabilites such as learning, self-awareness and logical reasoning [24]. Executive functioning, a cognitive capacity to execute a set of functions so as to achieve a desired goal, was found to be sensitive to shorter sleep time and fragmentation of sleep [25]. Many studies use a combination of polysomnographic and hormonal measurements to assess the effect of stress on sleep. For example, in a study on post traumatic stress disorder (PTSD), an extreme manifestation of stress, a significant increase in awakenings during sleep was observed in PTSD patients compared to control patients [26]. Moreover, the number of these awakenings were positively correlated with levels of ACTH (adrenocorticotropic hormone), a key player in the HPA stress pathway, and the subjective perception of sleep depth [26]. ACTH and cortisol levels during the first half of the sleep were found to be inversely related to the amount of slow wave sleep [26]. Similarly, another study showed that functional alterations in the HPA axis may contribute to sleep disturbances in PTSD [27]. A significant increase in ACTH level was observed on administration of a compound called metyrapone, which blocks cortisol synthesis, and this predicted greater decreases in delta power electroencephalographic activity in PTSD patients [27]. Systolic blood pressure was found to increase in response to psychological stress, and this effect was amplified by sleep deprivation [28].

Parameters such as respiration rate and heart rate also tend to vary when a person is sleeping [2]. The snoring level is an important parameter which helps in deducing stress levels; it is measured in decibels as it is the sound that is produced when there is an unusual increase in the respiration rate per minute [29], [8]. Snoring under 50dB can be considered normal, but when there is snoring at levels higher than 50dB, the chances of experiencing stress and other health issues are high [29], [30]. Similarly, the respiration rate, or the number of breaths taken per minute, is considered to be healthy if it is between 15-17 breathes per minute (bpm), and respiration rate greater than this is indicative of stress [9], [31]. In the same manner, the heart beats 5-10 times slower than the usual heart rate when a person is sleeping [32]. The heart rate is considered normal if the beats per minute (bpm) are 44-54 and considered abnormal if the bpm observed is greater than 54-64 [33], [34]. Also, it is known that an adult should sleep for a minimum of 7 hours; insufficient sleep will lead to stress [35], [36].

The processing or analyzing of these factors is done and the final stress state, from among the five available states of a person, is displayed on the tracker available to the person. The available stress states are:

- High Stress State
- Medium High Stress State
- Medium Stress State
- Medium Low Stress State
- Low Stress State

Table II details the ranges considered in the parameters when a person is sleeping.

TABLE II: Parameterized Ranging

Snoring Range (dB)	Respiration rate (bpm)	Heart rate (bpm)	Stress State
50-80 dB	17-22 bpm	54-64 bpm	Low, Medium Low and Medium Stress State
80-89 dB	23-25 bpm	65-70 bpm	Medium High Stress State
90+	25+	70+	High Stress State

V. Implementation and Validation of Smart-Pillow

For the implementation of the idea proposed, Fuzzy Logic has been used. The basic Fuzzy type used is Mamdani type Fuzzy logic. The input parameters are 3 and their ranges are specified in Table II. The pictorial representation of the Mamdani type Fuzzy system is shown in Fig. 4.

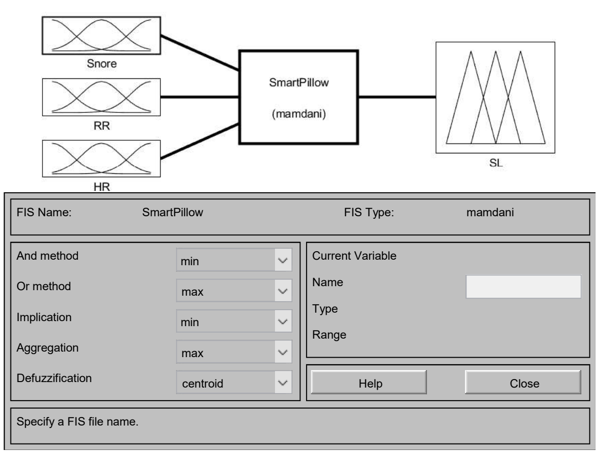

Fig. 4: Fuzzy Logic Designer View.

As there are 3 parameters and 5 sets of states, the total rules which can be generated are 5^3=125. So, the Fuzzy system is trained by a set of 125 rules and the output, i.e. the stress state, is defined in between the values 0 and 1. The individual range specification is as shown in Table III. The above implementation is shown in Fig. 5.

TABLE III: Fuzzy Output Range Specification

Stress State	Output Range
Low Stress State	0.00-1.00
Medium Low Stress State	1.01-2.00
Medium Stress State	2.01-3.00
Medium High Stress State	3.01-4.00
High Stress State	4.01-5.00

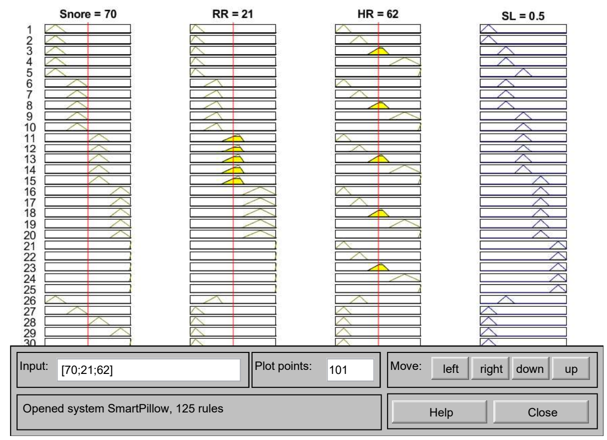

Fig. 5: Rules of Fuzzy Logic Design

A surface plot of the Fuzzy design response is shown in Fig. 6 which shows the variations of the output stress state with the variations in the input parameters.

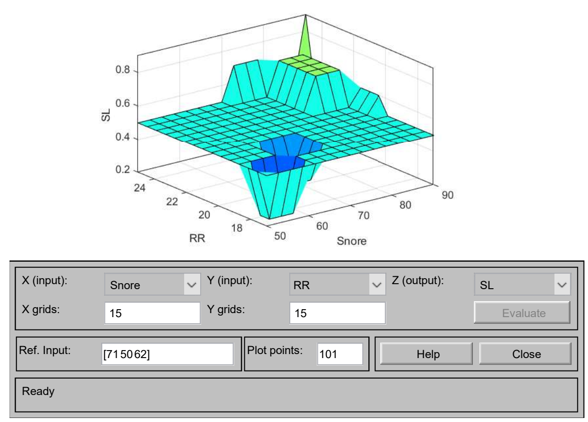

Fig. 6: Surface Plot of the Fuzzy System Response.

VI. Conclusions and Future Research

Five different classifications of stress based on measurement of sleeping parameters is presented in this work. The variations in the parameters are well explained along with the relationship of the stress with the considered parameters. The system is trained with a set of 125 rules and the outputs are produced accordingly. Implementation of the system incorporating Machine learning or deep learning concepts are suggestions for future research.

Most of the studies that discuss the relation of sleep impairment with stress are cross-sectional studies in which representative populations were sampled, and physiological/psychological tests were recorded only over a limited period of time, or once immediately after the occurrence of significant events (for e.g. stressful life events). During the course of the development of this tracker, long-term monitoring of physiological and psychological parameters which determine the quality of sleep, may help in generating longitudinal data, i.e. data pertaining to stress and sleep of individual subjects over a long period of time. This may help in pinpointing the advent of physiological or psychological markers of sleep impairments, indicative of stress [3]. This is analogous to specific biological molecules called "biomarkers" that help in the diagnosis of diseases. This will also help predicting the eventual development of several stress-related disorders linked to sleep impairment, such as depression, cardiovascular disorders, migraine and lung disorders [3].

This project may be further extended to devise appropriate interventional strategies to counter disorders whose etiology have at least been partially attributed to life style, for e.g. obesity. In a study conducted in a random sample of 1300 middle-aged men and women, shorter duration of sleep, higher incidence of subjective sleep disturbances and chronic emotional stress were observed in obese individuals [37]. Interventional strategies may include suggestions by the tracker on life style changes, such as various methods to prevent sleep onset latency. Further investigations in this direction may even lead to serious interventional strategies such as drugs that help in alleviating stress and restoring sleep affected by stress to its normal state. The compound, Octacosanol, a component of wheat germ oil, rice bran oil, and sugar cane, alleviates psychological stress induced by cage changes in mice and restores stress-affected sleep, by increasing the number of sleep episodes, decreasing wake episode duration, and reducing the levels of plasma corticosterone levels, thereby decreasing stress levels [38]. Hence, this smart health care project has immediate as well as long-term applications.

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