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

L. Rachakonda\textsuperscript{1}, S. P. Mohanty\textsuperscript{2}, E. Kougianos\textsuperscript{3}, K. Karunakaran\textsuperscript{4} and M. K. Ganapathiraju\textsuperscript{5}

University of North Texas, Denton, TX 76203, USA.\textsuperscript{1,2,3}
IISc, Bangalore, India.\textsuperscript{4} University of Pittsburgh, Pittsburgh, PA, USA.\textsuperscript{5}

Email: rl0286@unt.edu\textsuperscript{1}, saraju.mohanty@unt.edu\textsuperscript{2}, elias.kougianos@unt.edu\textsuperscript{3}, kalyanithepebble@gmail.com\textsuperscript{4} and madhavi@pitt.edu\textsuperscript{5}
Outline of the Talk

- Introduction
- Motivation
- Proposed Solution
- Novel Contributions
- A Broad Perspective of Smart-Pillow
- System Level Modeling of Smart-Pillow
- Implementation and Validation
- Conclusions and Future Research
Introduction

✓ Internet of Things

✓ Definition

- The Internet of Things is a network of devices where each device in the network is recognizable and connected.

- It can be thought of as the interconnection of uniquely identifiable smart objects and devices.
Introduction

✓ Applications of IoT
Research Motivation

✓ Is sleep an important factor of Stress?

The quality of sleep during the night reflects on productivity during the day.
Symptoms of Improper Sleep

- Back Pain
- Depression
- Feeling Overloaded
- Social withdrawal and isolation
- Neck Pain
- Weakness
- Frequent headaches
- Insomnia
- Weight gain
- Wild Mood Swings
How to Monitor Sleep?
Existing Products

- Apple Watch
- SleepScore Labs
- EverSleep
- Nokia Sleep

18th Dec 2018
Smart-Pillow Talk, ISES 2018
## Related Research

<table>
<thead>
<tr>
<th>Research</th>
<th>Method</th>
<th>Drawback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Choi et al [6]</td>
<td>Wearable</td>
<td>Importance of sleep to stress is missing.</td>
</tr>
<tr>
<td>J.-M. Lee et al [10]</td>
<td>Survey by Wearables</td>
<td>Study of sleep is mentioned but couldn’t establish a relationship among stress and sleep.</td>
</tr>
<tr>
<td>Zhenyu Chen et al [11]</td>
<td>Mobile Application</td>
<td>The accuracy of the system cannot be trusted as the user will have to manually enter the data also the relationship with stress is missing.</td>
</tr>
</tbody>
</table>
Issues of Existing Solutions

- Lack of Detection Accuracy of Sleep.
- Lack of having multiple stressors for effective sleep analysis.
- No Unified detection of the problem.
- Storage availability of the detected parameters for future usage.
- Self-Aware systems.
- Lack of knowledge on the relationship among stress and sleep.
The Research Question Addressed in this Paper

- How to have a non-invasive, optimized, IoT enabled system which detects the stress level variations based on the sleeping parameters, analyses the data at the user end (at IoT-Edge) and stores the data at the cloud end (at IoT-Cloud)?
Proposed Solution: Smart-Pillow

✓ Schematic Representation of Smart-Pillow.

- This research proposes the idea of a Smart-Pillow connected to a wireless tracker as a device to help monitor sleeping habits and let the user know using a wearable.
Novel Contributions

- A continuously monitoring battery optimized device which gets activated only when a person is lying on a 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.
Issues Addressed in this Research

- Advancement through this paper in Electronics.
- Significant Improvement in the Accuracy of Sleep Analyses.
- Considered Multiple Stressors for the assessment.
- Provided cloud storage access for future purposes.
- Proposed a self-aware system which is intelligent enough to establish a relationship between stress and the sleeping habits.
- An edge level system is presented with which the performance, accuracy and stabilization of the system can be maintained.
A Broad Perspective of Smart-Pillow

✓ Broad Conceptual View of Smart-Pillow.
Architecture of Smart-Pillow

Sensor Input Unit

Processing Unit

Sleep Tracking Unit

Parameter Range Comparison Unit

Parameter Analysis Unit

Stress State Prediction Unit

LSS
MLSS
MSS
MHSS
HSS

User Display

UI Unit
Flow of Smart-Pillow

Pressure Sensor

Timer

Yes

On

No

Idle State

Noise Sensor

Heart rate Sensor

Respiration rate Sensor

Track Sleep

No

Parameter Range Comparison

On

No
Flow of Smart-Pillow

1. Analysis
2. Stress State Prediction
3. Storage

- Yes
- Timer data
- Mobile Application
- Display Unit
Dataset Acquisition

The Data at the sensor units are:

- **Snoring Rate**- When Snoring level exceeds 50dB, the chances of having stress is high

- **Respiration Rate**- Number of breathes per minute (bpm) when exceeds 15-17, can cause stress

- **Heart Rate**- If there is an observed heartrate more than 54-64 beats per minute (bpm), the chances of stress are high.

- **Number of hours of Sleep**- Minimum of 7 hours of sleep is required to maintain a healthy life.
### Parameter Ranges

<table>
<thead>
<tr>
<th>Snoring Range (dB)</th>
<th>Respiration Rate (bpm)</th>
<th>Heart Rate (bpm)</th>
<th>Stress State</th>
</tr>
</thead>
<tbody>
<tr>
<td>50-60</td>
<td>17-19</td>
<td>54-57</td>
<td>LSS</td>
</tr>
<tr>
<td>60-70</td>
<td>19-21</td>
<td>57-60</td>
<td>MLSS</td>
</tr>
<tr>
<td>70-80</td>
<td>21-22</td>
<td>60-64</td>
<td>MSS</td>
</tr>
<tr>
<td>80-89</td>
<td>23-25</td>
<td>65-70</td>
<td>MHSS</td>
</tr>
<tr>
<td>90+</td>
<td>25+</td>
<td>70+</td>
<td>HSS</td>
</tr>
</tbody>
</table>
Parameter Analysis

- Timer data
- Snoring Sound Range
- Respiratory Rate Range
- Heart Rate Range

Fuzzy Logic System → Stress Level Prediction

- High Stress State (HSS)
- Medium High Stress State (MHSS)
- Medium Stress State (MSS)
- Medium Low Stress State (MLSS)
- Low Stress State (LSS)
Fuzzy Logic-Designer’s View

- A Mamdani Type Fuzzy Logic System is used.

- As there are 3 parameters and 5 sets of states, the total rules which can be generated are $5^3 = 125$. 

![Diagram showing Fuzzy Logic System setup](image)
# Fuzzy Output Range Specification

<table>
<thead>
<tr>
<th>Stress State</th>
<th>Output Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Stress State (LSS)</td>
<td>0.00-0.20</td>
</tr>
<tr>
<td>Medium Low Stress State (MLSS)</td>
<td>0.21-0.40</td>
</tr>
<tr>
<td>Medium Stress State (MSS)</td>
<td>0.41-0.60</td>
</tr>
<tr>
<td>Medium High Stress State (MHSS)</td>
<td>0.61-0.80</td>
</tr>
<tr>
<td>High Stress State (HSS)</td>
<td>0.81-1.00</td>
</tr>
</tbody>
</table>
Rules of Fuzzy Logic Design

- The representation of rules and its implementation in the Fuzzy Designer is shown.

- The 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.
Sleep Parameters-Surface Plot

✓ Surface Plot of the Fuzzy System Response.

- The 3D plot of the system is represented here.

- The values Stress Level (SL), Respiration Rate (RR) and Snoring rate are represented along with their boundaries as a validation of the system.
# Comparison with Existing Research

<table>
<thead>
<tr>
<th>Name</th>
<th>Approach</th>
<th>Features</th>
<th>Drawback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fitbit [14]</td>
<td>Wearable</td>
<td>Heart rate monitor, sleep stages monitor</td>
<td>Does not manage stress with sleep.</td>
</tr>
<tr>
<td>Xiaomi Mi Band 3 [16]</td>
<td>Wearable</td>
<td>Pulse Monitor</td>
<td>Does not manage stress with sleep.</td>
</tr>
<tr>
<td>Beddit [18]</td>
<td>Non-wearable</td>
<td>Monitors snoring</td>
<td>Does not manage stress with sleep.</td>
</tr>
<tr>
<td>This Paper</td>
<td>Wearable</td>
<td>Heart rate, Snoring, Respiration rate</td>
<td>Establishes a relationship between sleep and stress, allows the user to have a control over the stress level variations.</td>
</tr>
</tbody>
</table>
Conclusion and Future Research

- Five different classifications of stress based on measurement of sleeping parameters is presented in this work.
- This method helps in improving and controlling the overall stress levels of a person.
- Implementation of the system incorporating machine learning or deep learning concepts are suggestions for future research.
Thank You !!!