Context-Aware Mobile Application for Mitigating Sleep Deprivation-Related Vehicular Traffic Accidents

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ABSTRACT

About 40% of U.S. adults face sleep deprivation, stemming from factors like work commitments and medication side effects [1]. Despite having an impact on crash risk comparable to alcohol impairment, sleep deprivation is often underestimated in its role in motor vehicle accidents. Our proposed solution is a context-aware mobile app that analyzes biometric sensor data, the user's sleep schedule, and other relevant tested statistics to recommend the optimal mode of transportation—public or personal vehicle—based on safety considerations. The app assesses biomarkers like heart and respiratory rates, incorporates user reaction tests, and evaluates overall mental performance to gauge the commuter's ability to safely operate a vehicle. Based on these various factors, the application computes and presents both a crash risk and a transportation recommendation to the user.

1. INTRODUCTION

Sleep deprivation is a pressing health issue in the United States, impacting millions of adults [2]. Despite the widespread underestimation of its severity, alarming statistics reveal that drowsy driving is a significant contributor to traffic accidents. To address this critical problem, a context-aware mobile application has been developed. This innovative solution utilizes biometric sensor data, sleep schedules, and relevant diagnostic information to comprehensively analyze the user's mental performance and driving ability. Users can record various metrics such as heart rate, respiratory rate, sleep duration, flu-like symptoms, and reaction time. A fuzzy logic controller processes the recorded values to generate a calculated reaction time. This information is used to predict the chance of the user crashing if they should drive, which enables the application to recommend the most suitable method of transportation based on the user's driving ability.

The report on this initiative is structured into several sections. It begins by highlighting the magnitude of sleep deprivation as a pervasive health concern, particularly in the United States [1]. Following this, the paper covers the general architecture of the application, and how different components integrate with each other. The paper then provides a look at the user interfaces of the major sub-applications, and explains how the app was implemented. The demonstration process for the app is then explained in more detail. Finally, the conclusion, successes, and future work related to the app are explored.

The mobile application aims to mitigate the risks associated with drowsy driving by providing real-time analysis of physiological indicators, sleep patterns, and reaction times. It respects user privacy and incorporates security measures to handle sensitive data responsibly. In instances where a user is deemed insufficiently alert for driving, the application recommends alternative transportation modes, contributing to public safety. Beyond risk mitigation, the app serves as an educational tool, raising awareness about the dangers of drowsy driving and promoting safer choices. Overall, this innovative application embodies the concept of a guardian angel in mobile computing, leveraging technology to enhance user safety and minimize the risks associated with accidents caused by drowsiness. The application’s thorough integration with available sensors allows it to be contextually aware and minimally invasive of the user’s privacy while still providing additional safety to the user.

2. ARCHITECTURE

In response to the critical issue of drowsy driving and its implications for road safety, our application aims to provide a multifaceted solution by considering physiological indicators, reaction times, and environmental factors. The architecture of our safe driving application is detailed in Figure 1, encompassing key modules for user input, reaction time assessment, data processing, crash prediction, and personalized travel recommendations.

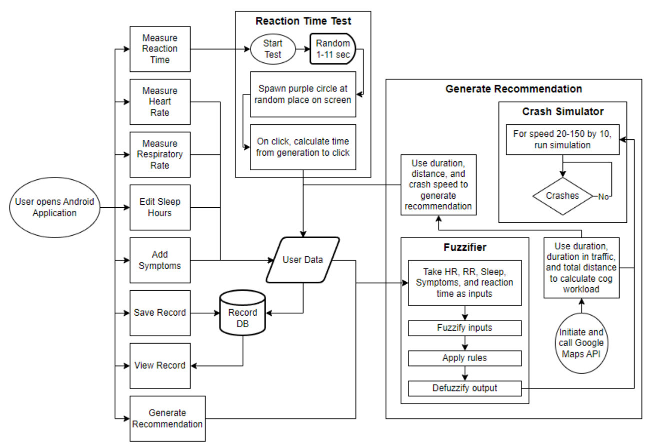

Figure 1: Safe Driving Application Architecture

2.1 User Input Module

The application's home page serves as a central hub for users to input critical physiological metrics, including heart rate, respiratory rate, sleep duration, and symptom logs. To accurately capture the user's heart rate, an algorithm analyzes a provided video of the user's finger against their phone's camera, estimating pulse by examining changes in picture saturation. The respiratory rate is measured using the phone's built-in accelerometer, providing a comprehensive overview of the user's physiological state.

2.2 Reaction Time Assessment

The application incorporates a reaction time test that users can engage in directly from the home screen. This test generates a random time interval between 1 and 11 seconds, prompting the user to click on a displayed dot as quickly as possible. Notably, the recorded reaction time is adjusted by a fixed duration of 250 milliseconds to account for runtime and mitigate potential bias.

2.3 Fuzzifier

To enhance the accuracy and generalization of the user's reaction time, a fuzzifier processes the input values from the user, refining the data for subsequent modules. This component acts as a crucial intermediary step in translating raw physiological metrics into a more comprehensive representation of the user's alertness.

2.4 Crash Simulator

Utilizing the generalized reaction time and current road conditions, the crash simulator predicts a user's likely speed limit at which a crash may occur. This predictive analysis forms a pivotal component of the application's preventive strategy, allowing for proactive measures to be taken based on potential risk scenarios.

2.5 Recommendation Generator

The recommendation generator utilizes the predicted crash speed, travel distance, and real-time road conditions to formulate personalized travel recommendations for the user. Drawing upon statistical data and user testing, these recommendations are optimized to ensure the user's safety and well-being, especially in cases where driving is deemed unfit.

2.6 Data Storage

The application provides users with the option to save their inputs and generate recommendations to a local database. This feature enables users to review their historical data, offering insights into their symptoms and fitness for driving over time.

3. THE APPLICATION SUITE

The application suite for our mobile app consists of five applications. The homepage serves as the landing page for the user. The symptoms panel allows for the user to input their level of various symptoms. The reaction time test generates a baseline reaction by testing the user. The recommendations page allows the user to generate a travel recommendation. The view records page allows the user to view past saved records.

3.1 Homepage

As seen in Figure 2a, The homepage serves as the main page for the application. While not necessarily a full sub-application, it was included in the section due to the relevance of its various integrated features. From the homepage, the user can measure their heart rate and respiratory rate, record their sleep, and save their current record. The heart rate is calculated by uploading a view of the user's finger over the camera, and using a saturation algorithm to determine the speed at which the red "pulses". The respiratory rate has the user place their phone on their chest, and uses the acceleration to determine the speed of the breathing. The sleep hours are input using a text field with additional data input safeguards in place. These are all parameters used in calculating the modified heart rate of the user, which is used in generating the travel method recommendation.

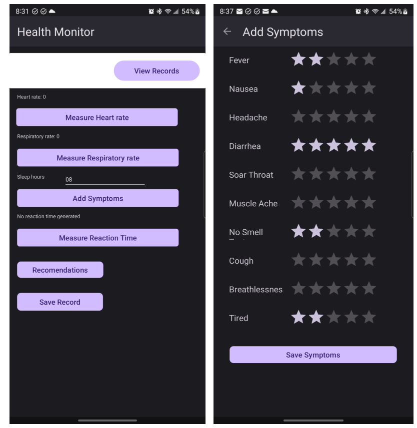

Figure 2: a) Homepage View; b) Symptoms Input

3.2 Symptoms Input

The symptoms input is a GUI that allows the user to input and save their symptoms. For each symptom in a given list, the user is able to select from a range of 1-5 stars, or abstain if the symptom is not relevant. The exact format can be seen in Figure 2b. Once the user is done they can save their symptoms, or if they mess up, they can reopen the symptoms page to start anew. The user can also write over old symptoms if something needs to be updated.

3.3 Reaction Time Test

The reaction time test is a two page application. The first explains the reaction time test, and the second runs it. The test is designed to be as simple as possible in order to focus exclusively on reaction time. The test starts, and the page remains empty for a random, but limited, amount of time. After this time is up, a purple circle displays on the screen. An example of this is shown in Figure 3b. The user taps the circle, and the time between the appearance of the circle and the tap is recorded. The user is then returned to the homepage, and the reaction time is displayed.

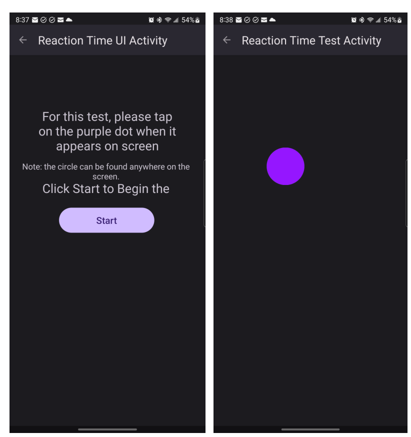

Figure 3: a) Reaction Test Description; b) Reaction Time Test

3.4 Recommendations Page

The recommendations page is the main component of the application, and allows the user to use their biometric data to generate a travel recommendation. The UI contains two input fields and a button. The user inputs a starting location and an end location, and presses the button to generate a recommendation. Behind the scenes, the app uses a fuzzy logic module to process the road condition, heart rate, respiratory rate, sleep hours, symptoms, and baseline heart rate into a modified reaction time more representative of their current state. This modified reaction time is then used in a crash simulator to determine the speed at which the user crashes. This, in turn, is used in conjunction with the distance to the destination and the road condition to generate a personalized recommendation for travel. The recommendation is then displayed to the user, and stored for later use if the user saves their record.

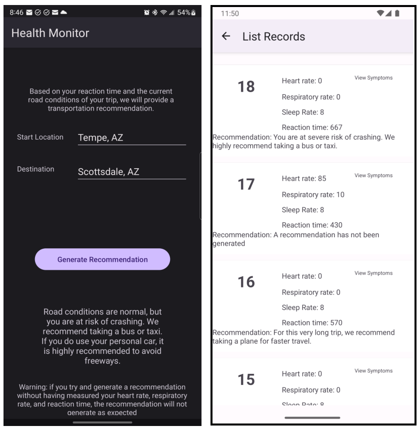

Figure 4: a) Recommendation page with generated recommendation; b) Records view

3.5 View Records

The final app is a record viewer. At any point while using the application, the user can store all information about their current record to the application's internal database. These records can be viewed through the record viewer button on the homepage. The viewer, as seen in Figure 4, displays all the records in a scrollable format with the most recent records at the top. Each record is also labeled with a label number for easy identification and to inform the user of how many records they have recorded.

4. IMPLEMENTATION

This application retrieves vital information from numerous biomarkers and physiological indicators by utilizing the assortment of sensors in a general smartphone. The calculation of the heart rate utilizes a fundamental implementation of photoplethysmography which is an optical technique that detects volumetric changes in blood in peripheral circulation [4]. As previously mentioned in the application suite section, the heart rate is calculated by a color saturation algorithm that detects variations of red pixels of a video recording of the user's finger over the flash and camera of the smartphone. The accelerometer of the smartphone is used to determine the user's respiratory rate by analyzing the user's chest movement and fluctuations in acceleration. A database created using SQLite is implemented to store the accumulated data to which the user can view previous records. Furthermore, a fuzzy logic controller is constructed to analyze the compiled information to generate a simulated reaction time according to the user's cognitive state. The fuzzy logic controller is programmed in Java and creates multiple membership functions to determine the impact of each indicator on a user's reaction time. The application utilized Apache Commons, a prominent Java library composed of effective mathematical and statistical functions, to simulate the probability of a traffic accident using the reaction time calculated by the fuzzy logic controller. Finally, the application integrates the Google Maps API to monitor road and traffic conditions from the origin and destination addresses provided by the user. With the examined calculations compiled from the fuzzy logic controller and the simulation, a recommendation algorithm is implemented to present the user with their recommended mode of transportation.

5. DEMONSTRATION

The demonstration setup involves the application running on an emulator. The emulator is pre-loaded with a video of the presenter holding their finger over the camera, which is used for the heart rate measurement. The presenter will use the emulator to test the heart rate and respiratory rate. The heart rate will work, and the respiratory rate will default to 10, the minimal expected respiratory rate for a human. The respiratory rate has been tested on a physical device and works properly, but using a physical device makes demonstration more difficult. The hours slept, symptoms, and reaction time test can be done live. After everything is complete, a reaction is generated and saved as a record. The record, and other previously saved records, can then be viewed. This entire process is completed on the laptop running the simulator, which is being projected to all viewers.

6. CONCLUSION

Recent research of the extremity of sleep deprivation in traffic accidents emphasizes the need for innovative solutions to mitigate associated risks [3]. The context-aware mobile application represents a promising approach to enhance driver safety by leveraging biometric sensor data, sleep duration, and significant diagnostic information. Through a comprehensive evaluation of the user's mental performance from various biomarkers and a reaction test, the application generates personalized recommendations of transportation methods to consider the safety of the user and the general public. The acknowledgment of the crash risk along with the recommended mode of transportation assists the user in making informed decisions and reducing the impact of sleep deprivation in traffic environments. Further contributions can be integrated to improve the performance and usability of the application. A design feature that was not implemented due to time constraints is calculating the typical heart rate and respiratory rate of the user from multiple uses of the application. This design implementation can detect unusual variations of the user's heart and respiratory rates to efficiently evaluate the user's cognitive state. Overall, the application encompasses the vigilant nature of a guardian angel by diligently monitoring and assessing intricate physiological indicators to not only provide personalized recommendations for transportation methods but also aid users in making informed decisions to mitigate the harmful effects of sleep deprivation on traffic safety.

7. REFERENCES

[1] Junghaenel, Doerte U, et al. "Demographic Correlates of Fatigue in the US General Population: Results from the Patient-Reported Outcomes Measurement Information System (PROMIS) Initiative." Journal of Psychosomatic Research, U.S. National Library of Medicine, Sept. 2011, www.ncbi.nlm.nih.gov/pmc/articles/PMC3744100/#:~:text=The%20prevalence%20of%20fatigue%20in,reported%20being%20fatigued%20(2).

[2] Gottlieb, Daniel J, et al. "Sleep Deficiency and Motor Vehicle Crash Risk in the General Population: A Prospective Cohort Study." BMC

Medicine, U.S. National Library of Medicine, 20 Mar. 2018, www.ncbi.nlm.nih.gov/pmc/articles/PMC5859531/.

[3] Cai, Anna W T, et al. “On-Road Driving Impairment Following Sleep Deprivation Differs According to Age.” Scientific Reports, U.S. National Library of Medicine, 3 Nov. 2021, www.ncbi.nlm.nih.gov/pmc/articles/PMC8566466/.

[4] Cheriyedath, Susha. "Photoplethysmography (PPG)." *News-Medical.net*,27 Feb. 2019, www.news-medical.net/health/Photoplethysmography-(PPG).aspx#:~:text=Photoplethysmography%20(PPG)%20is%20a%20simple,related%20to%20our%20cardiovascular%20system.