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Analytical Study Serving Technical Features Extraction and Classification for most recent Smartphone-based Sleep Monitoring Applications

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Abstract—
Purpose*: In this study; the author explains and shows the importance of selection and extraction the technical features of Smartphones' apps regarding sleep-monitoring and sleep-analysis, and the technical features' selection and extraction impact on simplifying the features classification based on the most important sleep disorders screening and diagnosis symptoms.*
Methods*: by taking an in-depth analytical survey study and screening for most recent sleep-monitoring apps through the period from June -to- September 2024, and enumerating the common technical features of the sleep-monitoring apps related to the screened symptoms of sleep disorders and sleep-analysis studies. The study's author examined 145 of the most recent sleep-monitoring apps, and extracted the common technical features related to the most concerning sleep-disorder screened symptoms, then classifies the extracted features into categories. Moreover, the author conducted a statistical analysis for the extracted features to measure the number and percentage of the most recent sleep-monitoring apps that offer those extracted and classified technical features.*
Results*: a total of 145 most recent sleep-monitoring related apps were examined at first in the study which took place during the period from June – to - September 2024 focusing on 22 major technical features of sleep-monitoring apps, 35 apps (24.14%) were excluded from the study due to irrelevant design purposes, while 12 apps (8.27%) were excluded for duplication in the two major app stores (Apple Store and Google Play), then another 18 apps (12.41%) were excluded due to low usage and low rating during study period. At last, another 19 apps (13.1%) were excluded from the study because they did not meet the designed requirement values of the sensors' threshold-based features or pattern recognition-based features. Finally, 61 apps (42.07%) satisfied all the applications' inclusion criteria, and statistical model built through the extracted technical features in the study.*
Conclusions*: despite that there are hundreds of approved smartphones' sleep-monitoring and analysis applications; this analytical study evaluates, examines and analyzes the major common 22 technical features in 61 of the most recent apps with users' most highly rated apps in Apple and Google play stores with several advantages and beneficial features, including smart alarms and sleep aids. However, an in-depth content review of apps that met the inclusion criteria revealed that sleep-monitoring applications can utilize more improvements in technical features design and implementation.*
Keywords— *sleep analysis, sleep apps, sleep monitoring, sleep disorder screening, sleep statistics, technical features.*

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I. Introduction

HEALTH ASSESSMENT as a part of human activity observation and monitoring is one of the major sections of the assistive technologies and healthcare applications in which "Human Activity Recognition" (HAR) plays a crucial role (Anguita, D, et al., 2020, pp.216-224). Furthermore, sleeping is a natural and biological need for humans that occupies between 25% and 40% of the day for humans, and considered an influential factor leading to numerous health problems (Cappuccio, F, et al., 2010, pp.414-420). For instance, sleep disorders such as short sleep duration, wakefulness, anxiety, snoring, sleep apnea, and restless leg patterns (Adams, RJ, et al., 2017, pp.35-42) In addition; sleep disturbance is widely spread and affects 35% - 48% of adults (Baglioni, C, et al., 2011, pp.10-13). Furthermore, smartphones and applications tools have been rife and very common in popularity, with 94% ownership as first quarter of 2024 (Al Mahmud, A, et al., 2022, pp.21-24). As artificial intelligence (AI) along with microelectronic sensors technologies are continuously developing and evolving many mobile phones' applications utilizing a built-in microelectronic sensors (accelerometer) to measure users' movements and vitals during their sleep, then measured data can be used in an algorithm to estimate sleep time and sleep quality (

Anguita, D, et al., 2020, pp.200-203), which leads to smartphone sleep-trackers have been developed as a self-management strategy for people with sleeping disorders. Apple Store and Google Play are the major mobile app stores in the world, they have over 3.82 million and 2.6 million apps, respectively (Avci, A, et al., 2023, pp.1-10). It was proven in earlier studies in 2021 and 2022 that; "sleep quality" is a measure of how well an individual can sleep which is considered a self-satisfaction with all aspects of the sleep experience. According to a recent study in 2022; most healthy adult users of age 20-to-45 years whether males or females; need between seven and nine hours a night to wake up feeling well-rested, but it depends on exactly what happens during those hours regardless of any mental dysfunctions. Which means "sleep quality" is crucial to get the essential physical, mental, and emotional benefits (Banitalebi, M, et al., 2020, pp.13-17). Therefore; "sleep quality" as an important measure in this study, it should be stated that there are five characteristics generally assessed to measure sleep quality which are; sleep latency, sleep waking, Wakefulness After Sleep Onset (WASO), and Total-Sleep-Time (TST) and Time-in-Bed (TiB) which are also crucial to calculate sleep efficiency (Molloy, A, et al., 2021, pp.20-24); all of which determine whether sleep quality is good or not, and hence are taken to consideration of this study as supporting technical features and inclusion / exclusion criteria of sleep monitoring apps under study.

HAR is a system model that receives the human movements and vitals measured by the "accelerometer" sensors as input, then it manages and analyzes the received data to return the classification of the activity as an output of the HAR system based on the referenced threshold values or baselines defined in the system (Kaghyan, S, et al., 2022, pp.148-152). Hence, one can say that; HAR common phases of operation to be data acquisition, feature extraction, and human activity classification. In data acquisition phase; various modern types of sensors built-in smartphones' microelectronic circuitry can be used such as vision-based motion sensors and inertial sensors which with nowadays technologies can capture a highly accurate data. Then, in the next phase; the acquired data will be processed to extract a low-level descriptors (LLD) which can fully describe and represent various human activities during sleeping, which consequently serve as a HAR system accurate inputs. After that, to accurately differentiate between the various human activities related to the acquired data during sleep; several classification and differentiation methods have been developed such as Support Vector Machines (SVMs), Convolutional Neural Networks (CNNs), Decision Trees, and k-nearest neighbors (Chernbumroong, S, et al., 2020, pp.61-67) (Kaghyan, S, et al., 2022, pp.148-152). It should be taken to consideration that; the HAR system efficiency depends upon accuracy and complexity of feature extraction process, plus the number of selected objective features. Furthermore, it is important to note that as stated in the literature; increasing the number of selected features does not necessarily improve the HAR system efficiency (Reed, D, et al., 2016, pp.263-266) (Robbins, R, et al., 2020, pp.46-52), rather the selected features should be objective and relative to the goal of the smartphone app.

II. PROBLEM STATEMENT AND OBJECTIVES OF THE STUDY

An in-depth survey and content review analysis of smartphones applications must be conducted based on the available information on the applications' developers' websites along with written descriptions of sleep-monitoring & analysis apps in the two major stores; Apple and Google Play stores. taken to consideration; that in order to accurately extract and classify the most common technical features; an in-depth content analysis of the features that are widely used in sensor-based activity recognition system must be done first, then an accurate feature selection process based on statistical analysis to identify and measure the most technical feature that are common and widespread among most recent sleep-monitoring apps. Therefore, the scope of this study aims to analyze the same information on the apps developers' websites and Apple – Google Play stores that are available to consumers when considering an app purchase. Also this study emphasizes 22 of the common technical features among the most recent smartphones sleep-monitoring apps. In conclusion this study aims to review and analyze Smartphones' (iOS and Android) sleep apps to explore their technical features and functionalities in order to find out about their effectiveness in monitoring users' sleep activity utilizing classification of the 22 common technical features of most recent sleep-monitoring apps. Therefore; for achieving the study main objective it is been a necessity to subdivide it into five specific objectives; Firstly, to thoroughly examine and explore smartphones' applications related to sleep-monitoring and analysis that are most recently available on the Apple store and google play store. Secondly, to analyze the technical features and discover the more common sleep app features. Thirdly, to build a classification of features. Finally, to promote the developers to design better sleep apps regarding technical features utilizing the new and evolving technologies in microelectronic sensors and software engineering.

III. METHODOLOGY AND STEPS

Systematic Search and Apps Selection Criteria

This paper focused on the most recent Apple iTunes and Android Google Play Stores for sleep related apps searching, as these are the most popular and used apps on smartphones during the period from June– to – September 2024 using the following keywords and search strings: sleep analysis, sleep apps, sleep monitoring,

sleep disorder screening, sleep statistics, sleep tracking, smartphone applications, technical features. At this point, a total of 145 smartphone' applications that were recently deployed for public commercial level in app stores related to sleep monitoring and analysis during the study period were included. In this phase, any smartphones' apps that weren't designed and deployed just for sleep related issues were excluded from the study. Apps belonging to the Apple iTunes and Android Google Play stores were identified, shared across both stores.

Applications Filtering and Technical Features extraction

In this step, all the included smartphones' applications from the previous step of apps searching and selection were double-checked for duplication in both iTunes and Google Play stores for any duplicated apps to be excluded. Furthermore, each smartphone sleep-related app was thoroughly examined either through the app store or the app developers' website to explore each technical feature provided by the app to the user/consumer and how it works to help the users. Through this level, a major 22 common technical features of the most recent sleep related apps became clear and will then be easily classified by the author later on into five categories or dimensions representing the purpose of the examined sleep-related apps.

Applications Screening and Eligibility

Exclusion Criteria

As stated previously, a total of 145 apps related to sleep-monitoring were firstly included in the study which took place during the period from June - to - September 2024 focusing on 22 major technical features of sleep-monitoring apps brightened up through exploring information available on the apps stores and developers' websites, 35 apps (24.14%) were excluded from the study due to irrelevant main implementation purpose, while another 12 apps (8.27%) were excluded for duplication in the two examined major app stores(Apple and Google Play) such as baby sleep monitoring apps: baby feeding & sleep tracker, Baby sleep diary tracker, Baby Tracker, Huckleberry Sleep Baby Tracker, Little Winks Sleep Tracker, Baby sleep tracker, Baby tracker - feeding. Then another 18 apps (12.41%) were excluded due to low usage and low rating during study period. After that another 19 apps (13.1%) were excluded from the study because they did not meet the designed requirement values of the sensors' threshold-based features (like: fall detection) or pattern recognition-based features (like: REM). In the event of a duplication, the study included the Apple Store app, as it had all the required information about the app including its date of release.

Inclusion Criteria

Each smartphone sleep-related application during the study period was thoroughly searched and examined by browsing through available information in both the Apple iTunes and Android Google Play stores and the app developers' websites. Data for each app was extracted and collected: app name, price, rating, number of reviews, author or developer name, technical features, and source (link to app webpage). Multimedia Appendix 1 provides full details of our sample applications. After four phases of app filtering and examination process; begins with irrelevant main implementation purpose other than sleep-monitoring apps elimination (1st exclusion phase), then duplication of sleep monitoring apps elimination (2nd exclusion phase), after that low usage and low rating apps elimination during study period (3rd exclusion phase), and finally apps elimination for not achieving the designed requirement values of the sensors' threshold-based features or pattern recognition-based features (4th exclusion phase). Therefore, an aggregate of 61 (42.06%) sleep-monitoring apps remaining to be thoroughly examined and analyzed. Figure 1 shows the flowchart of the app selection process emphasizing the inclusion and exclusion phases and criteria.

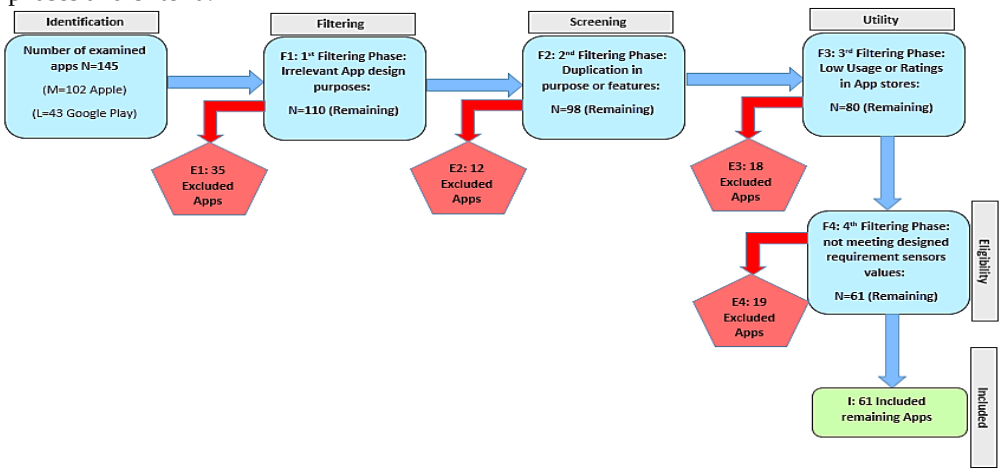

Figure 1. Flow Chart of Smartphones Applications' search strategy and screening algorithm

After the author examined and reviewed all the included apps; technical features were determined and collected based on the most popular Apple iTunes and Android Google Play stores' sleep-related apps. Then all the components and gathered information about the technical features of the most recent sleep monitoring apps were put in ascending order in one table in the following section (Results). Similar goal-oriented technical features are linked and categorized together in one dimension or category that represents the purpose/ goal of the technical feature, and the technical categories or dimensions are highlighted and given a title. For example, the attribute "User can set the alarm for bedtime and wake up time" is under the heading (Notifications feature). All features have been grouped into categories, each representing a different purpose served by the app. Moreover, Parts and related apps were checked repeatedly by the author to assure that there is no lack of information gathering or technical feature grouping.

IV. RESULTS

Consumers' Statistics and Reviews

The information about users' ratings and commentaries were gathered and obtained from the smartphones app stores on a scale of 1 to 5. Whereas; 13 (8.96%) Apple iTunes store applications and 5 (3.44%) Android Google Play applications are not included because they have no available ratings in the App stores. For apps with available ratings, the average rating for Apple iTunes store apps was 4.6, and the average rating for Android Google Play apps was 4.4.

Extracted and Classified Technical Features of the Included Sleep-monitoring Apps

After conducting an open statistical analysis as shown in Multimedia Appendix 2 for the Low-Level Descriptors (LLD) which lead to the common technical features of remaining included 61 applications; an aggregate of 22 technical features were extracted. Table 1 presents the main technical features, with the associated number and percentage of examined apps, and examples of applications that support these technical features, the table is arranged in a descending order. Furthermore, each technical feature is described in detail in the following sections.

TABLE I

MAIN TECHNICAL FEATURES OF THE INCLUDED APPS WITH EXAMPLES

Technical Features (number of Technical features: m=22)	Number of Apps: (n=61), n (%)	Selected app example
1.Smart Alarm	51 (83.60%)	BetterSleep
2.Sleep Tips / Coaching	46 (75.40%)	Sleep Cycle
3.Sleep Recording & Info Representation	43 (70.49%)	SleepScore
4.Sleep Sounds	41 (67.21%)	ShutEye
5.Timer	40 (65.57%)	Cycle alarm timer
6.Sleep Duration	40 (65.57%)	PrimeNap
7.Sleep Statistics	39 (63.93%)	Sleep Analyser
8.Stress Level Monitoring	37 (60.65%)	SleepWell
9.Sleep Efficiency (TST-To-Tib Ratio)	33 (54.09%)	Sleep Central
10.Accessibility & Exporting Data	32 (52.45%)	Calm
11.Fall Detection (for both babies and Adults)	30 (49.18%)	MotionX-24/7
12.Sleep Stories	30 (49.18%)	Sleepiest
13.Light Sleep	29 (47.54%)	SleepScore
14.Heart Rate	29 (47.54%)	Tracker sleep
15.Deep Sleep	29 (47.54%)	Muse S
16.Sleep Note	28 (45.90%)	Noisli
17.Bedtime Reminder	26 (42.62%)	Bedtime sleep
18.Sleep Talking Record	23 (37.70%)	Sleep Tracker – Sleep Recorder
19.Snoring	23 (37.70%)	Snore Lab
20.Rapid Eye Movement (REM)	22 (36.06%)	REM: auto sleep tracker
21.Breathing	21 (34.42%)	Pillow
22.Movement	21 (34.42%)	Sleep Bot

The first and most popular technical feature in this analytical review is the "Smart Alarm", developed in more than n= 51 (83.60%) applications. This feature allows waking up at a specific time and is sensitive to any sound and noise during sleep. The primary function of this feature is to wake people up from their deep sleep or nap, and it is sometimes used as a reminder. Allows the user to choose alarm ringtones and in some cases, can download music and set it as the alarm tone for waking up (Banitalebi, M, et al., 2020, pp.14-19). The second most common technical feature is "Sleep Coaching" and/or "Sleep Tips". It was developed in more than n= 46

(75.40%) applications. Sleep coaching apps can provide personalized tips and guidance to help you improve your sleep habits. These apps can track your sleep patterns, provide sleep-related education and offer customized sleep plans based on your goals and preferences. (Molloy, A, et al., 2021, p.22). The third most common technical feature is "Sleep Recording & Info representation"; It was developed in more than n= 43 (70.49%) applications. This feature allows the app to record sleep habits, sounds, and analytics and then represent them in a clear understandable tables and graphs (Chernbumroong, S, et al., 2020, pp.62-64). The fourth most popular technical feature is "Sleep sounds" feature, with n = 41 (67.21%) of applications. It carries several sounds, including nature, rain, and calm music. This feature works on good sleep and has been developed by several developers (Cappuccio, F, et al., 2010, p.415). The fifth common technical feature is the "Timer" feature, with n = 40 (65.57%) of the included applications. It measures the time of sleep start and time of waking-up and hence it helps measuring sleep duration (Casale, P, et al., 2020, pp.290-292). The sixth common technical feature is "Sleep duration", which is also developed in n = 40 (65.57%) of the included apps. This intelligent feature determines the time you need to go to bed and the time you need to wake up, along with information on a regular and healthy sleep pattern (Casale, P, et al., 2020, pp.292-294). The "Sleep Statistics" feature is supported, with n = 39 (63.93%) applications, it provides graphs for each night separately. It detects sleep stages and analyzes them comprehensively daily. This feature is based on the principle that sleep is not a one-track process but is instead a multiple wave consisting of peaks - which is a stage closer to awakening - and bottoms, which is the stage of deep sleep, and this process is repeated throughout the sleep period. It works by calculating these waves to find out the quality of sleep you got during the last night (Cappuccio, F, et al., 2010, pp.416-417). "Stress Level Monitoring" feature is supported, with n = 37 (60.65%) applications, it provides a defined two different stress scores, the daily stress score estimating the acute stress level of the previous day and the long-term stress score, which is the accumulated stress over the last days and weeks and which estimates the chronic stress level of a person (Muaremi, A, et al., 2013, pp.173-177). "Sleep Efficiency" feature which is supported with n = 33 (54.09%) applications, it refers to the percentage of time a person sleeps, in relation to the amount of time a person spends in bed. The percentage is calculated by dividing Total-Sleep-Time (TST) by Time-in-Bed (TiB) (TST-to-TiB ratio). Normal sleep efficiency is considered to be 80% or greater. For example, if a person spends 8 hours in bed (from 10 p.m. to 6 a.m), at least 6.4 hours or more should be spent sleeping to achieve an 80% or greater sleep efficiency. Most healthy and young adults have sleep efficiencies above 90% (Cappuccio, F, et al., 2010, pp.417-419). The tenth common feature is "Accessibility and Exporting Data" which is also a common feature included in our study with n = 32 (52.45%) of the included apps. whereas sleep app ownership is increasing exponentially, due to their accessibility and ease-of-use. Moreover, sleep apps may increase engagement with healthcare professionals, which may place additional strain on under-pressure sleep services (Casale, P, et al., 2020, pp.293-294). "Fall Detection", with n = 30 (49.18%), which is an important developed feature specially for children and elderly users; which can help alert emergency services when a hard fall has been detected via threshold-based motion sensors, and notify your emergency contacts, if sensors detect a hard fall and that the user have been immobile for about a minute, it taps user's wrist, sounds an alarm, and then attempts to call emergency services (Muaremi, A, et al., 2013, pp.177-180). The "Sleep Stories" feature is also supported by the n = 30 (49.18%) of the included applications. It stimulates creativity and develops imagination, and promotes psychological and emotional maturity to be able to sleep well. Improving communication skills and increasing focus and discipline are beneficial and healthy habits (Casale, P, et al., 2020, pp.294-296). The "Light sleep", and "Deep sleep" features are supported by n = 29 (47.54%) of the included apps; "Light sleep" is a tool that will help the user adjust the brightness level on his smartphone screen to avoid damaging his eyes in situations where the lighting is not appropriate (e.g., when user is browsing his phone at night before going to sleep), which will help user sleep better (Casale, P, et al., 2020, pp.291-292), while "Deep Sleep" is stage 3 in human sleeping; In this stage user's brain waves form very slow 'delta' waves, and his heart rate and breathing rate is at its slowest. This is the sleep that users need in order to wake up feeling refreshed the next day, as this is when the body undergoes those crucial processes for physical repair and recovery. The "Heart rate" feature is also supported by n = 29 (47.54%) apps. It analyzes heart and respiratory rate variance based on sleep movements to better understand your sleep behavior. users will also get data based on their sleep patterns, the ratio of light sleep to the comforter [15]. The "Sleep Note" feature is supported by n= 28 (45.90%) apps. It enables users to take notes and gives tips to overcome sleep disturbances. There are some examples of those tips that user can keep track of in Sleep Diary; like time you go to sleep, the time you sleep, it helps you review your daily habits (Chernbumroong, S, et al., 2020, pp.64-66). The "Bedtime reminder" feature is supported by n = 26 (42.62%) apps. This feature does not track user's sleep quality in the main form, but still; it offers useful features, such as giving reminders before bedtime and automatically setting the alarm for you, and the ability to customize your sleep schedule on certain days of the week (Chernbumroong, S, et al., 2020, pp.65-68). The "Sleep Talking Record" feature is supported by n = 23 (37.70%) of the applications. It records annoying sounds only, puts them in different audio tracks and sorts them in a timetable for easy browsing, and saves them on the smartphone without needing continuous recording throughout your sleep. It automatically records when a sound occurs, thanks to intelligent technology that records exactly what you say

while you are asleep and dreaming (Cappuccio, F, et al., 2010, pp.417-420). The "Snoring" monitoring feature is also supported by n = 23 (37.70%) of the applications. It enables you to analyze your sleep quality and detect if any problems impede your proper sleep. It only records snoring moments or disturbing sounds (Cappuccio, F, et al., 2010, pp.415-417), (Creber, R, et al., 2016, pp.34-37). The "Rapid-Eye-Movement" (REM) feature is supported by n = 22 (36.06%) applications. Sleep monitoring technology that is now generally available cannot accurately measure REM sleep, as researchers in sleep monitoring laboratories measure sleep stages with more sophisticated scientific equipment that usually includes devices sensors attached to a person's face and neck; to measure eye and brain activity, and other scientific variables used in the measurement (Cappuccio, F, et al., 2010, pp.417-420), (Chernbumroong, S, et al., 2020, pp.63-66). The "Breathing" feature is also supported by n = 21 (34.42%) of the applications. It helps to advise users and remind them of correct breathing methods. It also allows deep breathing exercises to get rid of sleep problems, in addition to straightforward lessons that teach the user about the benefits and importance of deep breathing (Casale, P, et al., 2020, pp.293-295), (Chernbumroong, S, et al., 2020, pp.63-65). The "Movement" feature is also supported by n = 21 (34.42%) apps. It monitors sleep cycles in addition to monitoring your movement during the day (Cappuccio, F, et al., 2010, pp.418-420).

As stated in a previous section, the major 22 extracted common technical features of the most recent sleep related apps became clear and can be easily classified by the author into five categories or dimensions representing the purpose of the examined sleep-related apps. Therefore, after feature extraction and analysis of all identified technical features (n = 22), as shown in Figure 2. These categories include; sleep cycle, notifications, sleep aids, vital signs and sleep disorders. The categories for each type contains a set of extracted technical features. The purpose is explained in the following section.

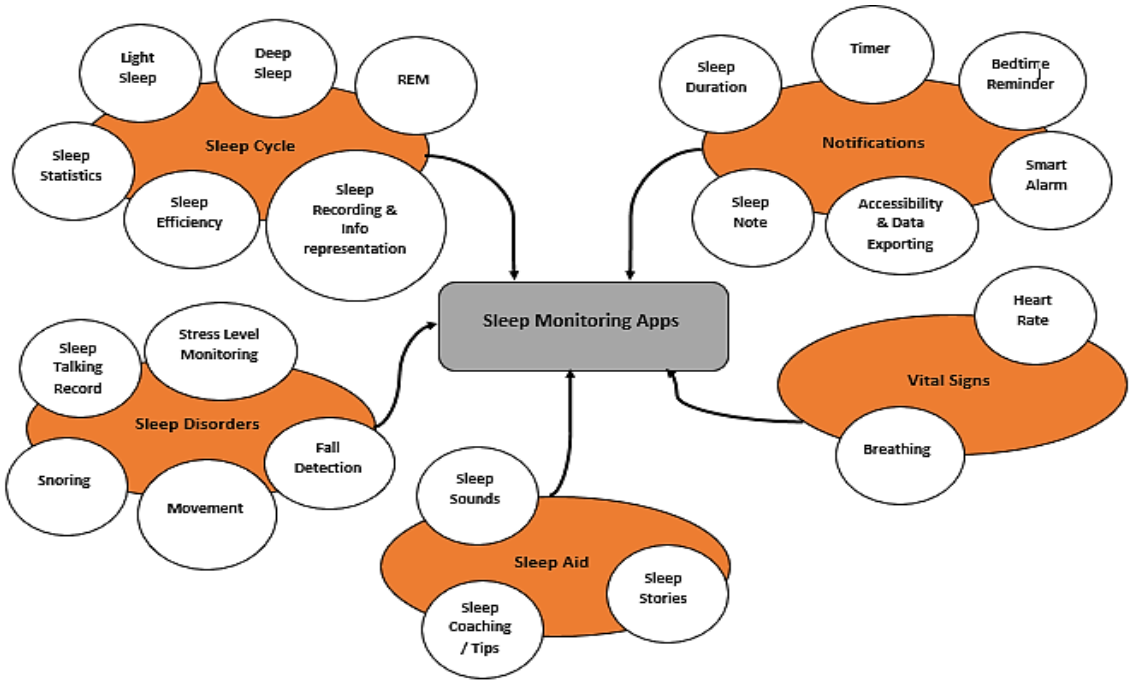

Figure 2. Extracted Technical Features Classification into Categories representing applications' purposes.

As shown in Figure 2. for the "Sleep Cycle" category, 6 of the 22 extracted technical features were found. The data generated from these apps helped their users improve healthy sleep habits; where the user can view statistics of data collected about his sleep in an app. The report includes total sleep time, number of awakenings in the night, and awake times. It also has a summary of your sleep stages. The technology also works to monitor sleep and record sounds made during sleep. It also determines sleep state to detect the time of falling asleep and waking up automatically and if the user is in a light sleep or a deep sleep. Detailed sleep data can be synchronized and displayed to give its users a peaceful sleep. As for the "Notifications" category, also 6 of 22 technical features were found to be relevant. It periodically reminds the user of information from certain specific apps. It enables users to set sleep reminders for a custom time and also lets you perform more actions automatically when they are absorbed. It works with a timer, stopwatch, and ring reminders for bedtime and wake-up times. As for "Sleep Disorders" category, 5 of the 22 technical features were found to be relevant. The data generated from these apps helped their users change the way they sleep. And maintain their health by recording the moments of snoring and movement and placing them in different audio tracks, and sorting them in a timeline. As for "Sleep Aid" category, 3 of 22 technical features were found to be relevant. helping to reduce distractions and increase focus through

meditation practice. Natural sounds help calm the mind, thus improving sleep patterns. Music and meditation produce more focus, better sleep, and less stress. It greatly facilitates the achievement of deep meditation, relaxation, and concentration. It also improves mental and physical health. Finally, for "Vital Signs" category, 2 of the 24 technical features were found to be relevant. The data generated from these apps helped its users track measurements such as blood oxygen, heart rate, sleep time, and breathing rate. He analyzes them into a timeline that details sources of sleep disturbance, such as coughing, snoring, or sleep interruption by lighting.

V. DISCUSSIONS

Principal Findings and Analytical Results

This comprehensive statistical study shows that sleep-monitoring smartphones apps differ in terms of the type of developer and background, major core 22 common technical features, purposes of use, privacy and security, accessibility, clinical foundation, and data integration towards therapeutic goal. This study reveals various apps developed by multiple developers and organizations, and analyzes the most common technical features as sleep data, calculating vital signs such as heart rate and breathing, detecting sleep disorders, and working to improve sleep quality. With the pervasive nature of smartphones, the use of health-related apps, including sleep analysis apps, will increase (Cappuccio, F, et al., 2010, pp.414-416). Several studies have found that sleep is linked to several health outcomes, including mood and blood pressure (Akbari, A, et al., 2021, pp.32-34), (American Psychiatric Association Website, Mental Health Apps). This study has focused on sleep-monitoring smartphones apps because they are accessible and inexpensive, making them more attractive to most people. Sleep apps have many features, but after analyzing them in the Apple iTunes and Android Google Play stores, we found that the most popular features are smart alarms, sleep coaching, sleep sounds, and Timers. One major attraction for users when downloading sleep apps is the smart alarm, which reportedly wakes the user at the optimal time (Cappuccio, F, et al., 2010, pp.417-420). smart alarm feature in 51 apps helps users wake up, refresh and invigorate in the morning at the perfect sleep cycle (light stage). Several "smart alarms" assume that sleep cycles are 90 minutes long.

Sleep quality and quantity are important factors for measuring sleep. Sleep monitoring apps can collect data to measure the quality and quantity of users' sleep. Detection of sleep disorders is one of the crucial functions offered by mobile applications; conditions in the early stage are much easier to treat than those later (Adrian, A, et al., 2020, p.51). As the result of this study show in Table 1. the sleep Duration feature in 48 apps, which tracks the sleep cycle by listening to sounds and analyses those sounds with the help of ever-evolving machine learning algorithms, presents the results and helps users to understand sleep with unique data analysis and graphs. Progressing multiple times through the sleep cycle, composed of four separate sleep stages, is vital to getting high-quality sleep. Understanding the sleep cycle helps to explain certain sleep disorders which can impact a person's sleep and health (Casale, P, et al., 2020, pp.289-293). In stage 1 (Light Sleep): the brain slows down, the body has some muscle tone, and breathing is regular. Stage 2: heart rate and body temperature both decrease. Stage 3 (Deep Sleep): brain waves at this stage, called delta waves, are at their slowest of the night. REM sleep feature in 21 apps; during REM sleep, brain activity is similar to awake, with loss of muscle tone except for the eyes, which move rapidly, breathing irregularly, and heart rate speed up (Chernbumroong, S, et al., 2020, pp.62-66). This study found no correlation between the polysomnogram findings and the sleep apps under study such as Sleep Cycle, Sleep Score, Pillow concerning sleep efficiency, light sleep percentage, deep sleep percentage, or sleep latency. Some smartphone meditation apps can help users measure sleep quality (Adrian, A, et al., 2020, pp.51-53), (Aji, A, et al., 2021, pp.21-22). There were 23 of the included apps in this study record snoring during users' sleep. These apps use the smartphone's built-in microphone to register during the night. Recording snoring during sleep may benefit clinicians examining patients who don't know about chronic snoring. Habitual snoring is an increased risk factor for CVD and may indicate obstructive sleep apnea. Although the apps are not intended for screening, their use in identifying snoring in specific populations could be helpful (Cappuccio, F, et al., 2010, pp.415-418). Nevertheless, 28 apps in this study can record sleep notes about sleep quality, any reasons for difficulty falling asleep, habits that may affect sleep, such as drinking coffee, eating late or exercising at night, and mood upon waking. Take brief notes about sleep, then discover how these factors affect sleep quality. Sleep doctors recommend using a sleep diary to collect information about a patient's sleep patterns. This is particularly critical for patients with hypersomnia due to poor sleep hygiene, insomnia, circadian disturbances, or phase shift (Cappuccio, F, et al., 2010, pp.417-419).

Research Study Limitations

While 61 apps were included and analyzed in this study, it is possible that some apps that met the inclusion criteria were missed. This research study for health apps related to sleep monitoring was limited to the major app stores Apple iTunes and Android Google Play. However, these stores are the largest global platforms for app distribution. Furthermore, the quality of these apps was not examined and rated Mobile apps also collect and manage users' sleep data, so data privacy becomes a common concern. In addition, this study did not explore

the specific written reviews of users; only the star ratings were provided without taking the written user comments into account it is unclear what factored into users' ratings. For instance, a user may have enjoyed the content of an app but experienced a technical fault and therefore decided to give the app a lower rating. Last, we did not directly explore the aesthetics or marketing of sleep apps in the Google Play store and Apple App Store, and future research should explore how these factors influence use of particular apps over others. The apps were not downloaded, thus more potential information regarding the app may be missing. Finally, short battery life is also a limitation of sleep apps, especially those that fit small sensors.

Comparison with Prior Works

This statistical study has collected and analyzed recent smartphones apps in the two major app stores (Apple iTunes and Android Google Play store) in the period from June – to- September 2024. During the study period the author has focused on the most common technical features regarding sleep monitoring apps which have been found to be 22 technical features, then a thorough statistical analysis is conducted by the author to determine the importance, impact, and frequency of these technical features in sleep-monitoring apps during the recent time of the study. Exclusion and inclusion criteria of included apps have been designed by the author concerning the technical features been analyzed, the irrelevancy of app main implementation purpose (other than sleep-monitoring), low star-rating or usage of apps in the developer's website, and duplication of apps from the same developer with similar features. Moreover, this study designed and conducted a specific and accurate content and review statistical analysis of the included apps based on the threshold and pattern recognition values defined in the built-in smartphones sensors, all information has been collected and reviewed from the apps developers' websites or from Apple iTunes and Google Play app stores.

VI. CONCLUSIONS

In conclusion, smartphones are an integral part of today's society specially with continuous growth of AI, Programming, and microelectronic sensors technologies; leading to sleep-monitoring applications have become very popular and easy to use. This analytical study only searched the two major app stores, the Apple iTunes and Android Google Play stores for sleep related apps as these stores considered the world's largest platforms for app distribution. Technology has increased awareness of sleep and its effects on health and functional outcomes, and mobile apps have become a popular tool for delivering sleep therapies. However, there is little evidence that the information provided by these apps is correct to support their usefulness. Multiple developers have developed sleep-related apps to monitor, measure and analyze sleep data, calculate vital signs, and detect sleep disorders. This study evaluated 61 apps and found that sleep-wake detection is unreliable enough to evaluate sleep efficiency and sleep quality since only 13 apps of 61 apps under study (21.31%) used sleep-wake detection technical feature, compared to sleep mapping features which are used in most of the apps under study (48 apps – 78.69%). The most popular aspects of sleep apps are intelligent alarms (notifications), sleep sounds, and timers. Apps that monitor sleep can collect information about users' sleep patterns, including their duration and quality, and provide services such as detecting sleep disorders using either threshold-based sensors, or pattern recognition algorithms. Although 61 apps were examined for this study, some of them likely met the requirements for inclusion. Users' sleep data is collected and managed by mobile apps as well, so data privacy becomes a common issue. In addition, only star ratings were provided in this search; no specific written user reviews have been screened. It is unclear what influenced user ratings without considering written user comments. For example, a user may have liked the app's content but had a technical problem, so he gave the app a lower rating. Finally, this study designed and conducted a specific content and review analysis of the included smartphones applications focused on detecting sleep disorders using threshold-based sensors or pattern recognition algorithms to acquire, measure, and analyze the Low-Level Descriptors (LLDs) forming baselines for the specific sleep disorder-based technical features.

However, future studies should investigate how these factors influence the use of certain apps over others, this study did not specifically examine the aesthetics or marketing of sleep apps in the Google Play Store or the Apple App Store. As the apps are not downloaded, more details may not be available. Sleeping apps should undergo a precise and intensive validation study and give more autonomy to their users over how their data is shared. Based on this study we found that most apps include intelligent alarm clock function and sleep recording function, but sleep-related physiological signal recording function accounts for a small proportion; that is the reason this study strongly recommends the applications' developers to focus and improve sleep-related both psychological and physiological signal recording function in most of their apps through utilizing sensors, AI, and machine learning new and advancing technologies.

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AUTHOR CONTRIBUTIONS

Nadir M. Abdelaziz contributed in conceptualizing the study and in data acquisition and aggregation process from the app stores and also in designing the analytical analysis to serve in extraction and classification of the common technical features of smartphone-based sleep monitoring applications, and manuscript revision. As well as in drafting the manuscript, and in conducting data acquisition, and analysis, designed for some of the threshold-based and pattern-recognition- sensor-based apps, and revised the obtained results

.

CONSENT FOR PUBLICATION

I, the undersigned, as the author of this paper, give my consent for the publication of identifiable details, which can include photograph(s) and/or videos and/or case history and/or details within the text ("Analytical Study Serving Technical Features Extraction and Classification for most recent Smartphone-based Sleep Monitoring Applications") to be published in the JOURNAL OF GLOBAL INFORMATION TECHNOLOGY MANAGEMENT.

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STATEMENTS AND DECLARATIONS

COMPETING INTERESTS AND FUNDING

I, the author of this paper, declare that I have not received any personal or organizational funding regarding the research or publication processes or any work reported in this article.

I, the author of this paper; declare that I have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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APPENDICES AND SUPPLEMENTARY MATERIALS

- Multimedia Appendix 1: Multimedia Appendix - Summary of all the studied Apps [PDF File]
- Multimedia Appendix 2: Multimedia Appendix - Common Technical Features of Sleep Monitoring Apps Statistical Analysis [Excel File]

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