Sleep Tracking Alarm

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1 Introduction

1.1 Objective

For some people, waking up in the morning is not a difficult task. They are ready to hop out of bed and start their day with little difficulty. For everybody else, being motivated to get out of bed at a good time without feeling groggy is not always easy [1]. Every night, people set their alarms on their phones to wake them up the next morning. Whether it's one single alarm or ten different alarms every ten minutes, the basic phone alarm is often not enough to wake up and to get out of bed. After a few nights it becomes a routine to turn off the alarm without even noticing and falling right back to sleep. It is clear that for some the basic alarm is not enough.

Our solution is a new type of alarm system that can get the user out of bed as well as make them wake up feeling energized. Our design is a wearable that goes on a person's wrist, paired with a camera system. The wearable system includes sensors to track sleep patterns which are used to determine best time to set off the alarm. It has an LED screen with buttons used to set a prefered wake up time interval. This is paired with the computer vision camera system. Once the alarm goes off, the camera system waits until it can confirm the person is standing in an upright position before turning off the alarm. This forces the user to get out of bed without turning off the alarm and falling back asleep. The wearable detects the user's body movement while they are sleeping using various sensors to determine whether they are in deep sleep (little to no movement) or in light sleep. We use this information to wake them up while they are in their lightest sleep during the preset wake up time interval, which is anywhere from 15 minutes to 60 minutes, in 15 minute intervals. Let's say a person wants to wake up by 8 am to be at work by 9. If they set their alarm interval to 30 minutes, the system will wake them up at 7:30 am if it finds they are in very light sleep, before they fall back into deeper sleep. Although they get a little less sleep, they will actually wake up feeling more refreshed by waking up at the end of a sleep cycle. This further motivates them to get up out of bed and stand up straight when the alarm starts ringing.

1.2 Background

According to a study done in the United States, 58% of people reported they spend more than five minutes in bed after turning off their alarm in the morning. Additionally, 57% say they still feel tired after waking up and only 33% describe their experience waking up as good [1]. Clearly, waking up is difficult for many people, and many wake up feeling tired or groggy. Turning off a phone alarm on the phone or hitting snooze is so easy. This does not force a person to get up and out of bed, it merely wakes them up for a small amount of time.

Many people wake up feeling tired due to waking up in the middle of deeper sleep cycles. Humans go through different sleep cycles while they sleep which range from very light sleep to deep sleep. Sleep cycles last around 90 minutes, as we drift from light sleep, into deep sleep, and back to light sleep. During lighter sleep people are relaxed but still restless, as they fall deeper into REM sleep, the body moves very little and heart rate is mostly slow [2]. Waking up in the middle of deeper sleep is difficult and disorienting [3]. The goal is to wake up the person by finding an optimal time; that is when the person is in light sleep according to their sleep trends. If we can wake up people when we know they are at the end of a sleep cycle, rather than at a set time, we believe people will wake up feeling more motivated to start their day.

1.3 High-Level Requirements

- Able to take various sensory inputs for higher accuracy and more reliability to detect if the user is asleep or not.
- Able to take the user's set alarm time and wake up interval from the wearable device, and find an optimal time to wake up the user based on sleep trends, with exact precision of hour and minute.
- The battery is able to last at least 12 hours (enough to cover one night of sleep).

2 Design

2.1 Block Diagram

There are three main parts to the design of our system. The most important being the wrist-wearable device, consisting of various sensors, a microphone, a speaker, a LCD screen, push buttons, and the microcontroller. Secondly, we have a computer vision module to study the user's posture when the alarm is triggered to confirm that the user is out of the bed.

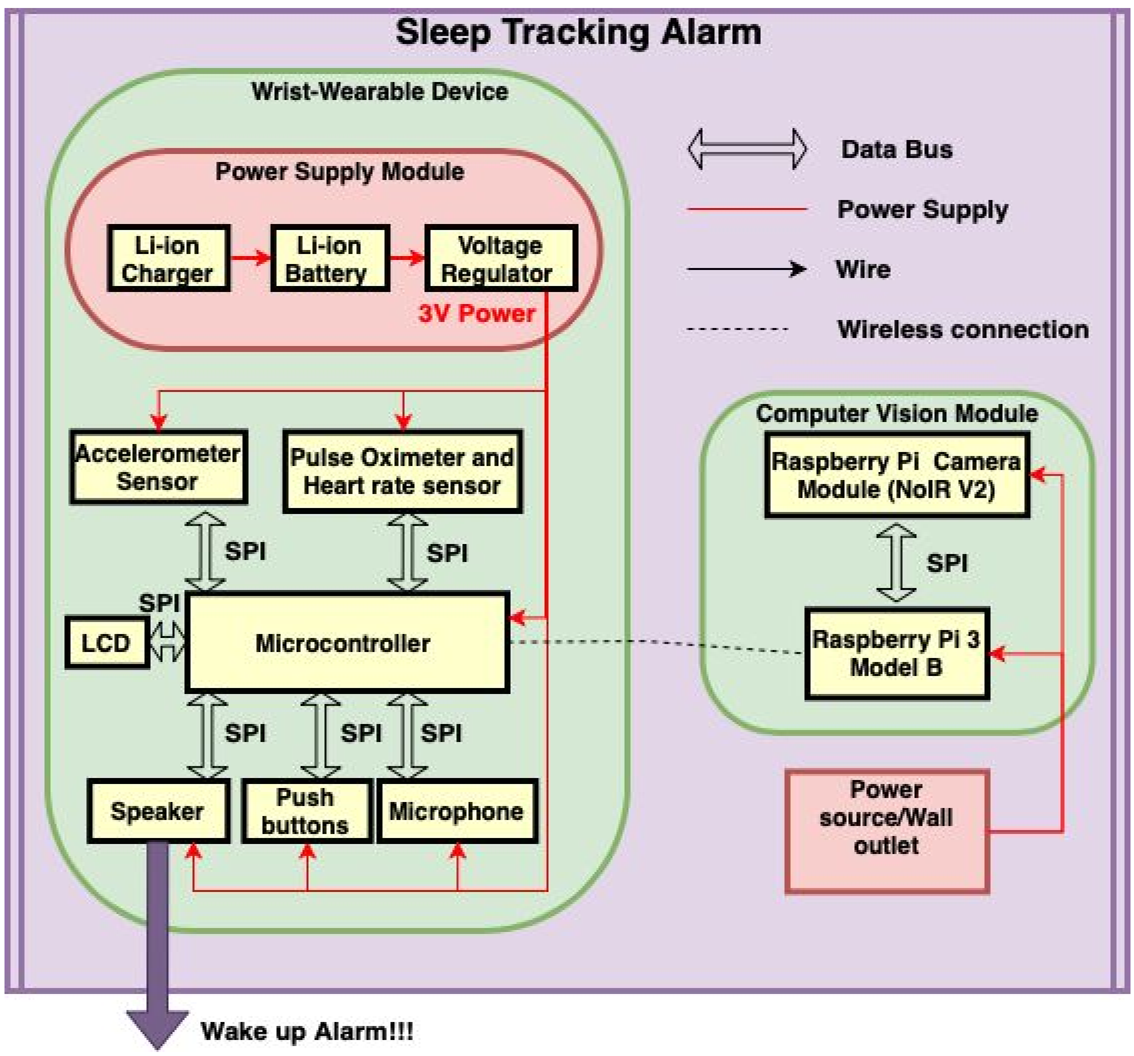

Figure 1. Block Diagram of Sleep Tracking Alarm, showing component level interfaces.

2.2 Physical Design

Figure 2 shows the physical design of the proposed sleep tracking alarm, consisting of the wrist-wearable watch and computer vision module. It shows an ideal setup of how the system is intended to be used. For example, the computer vision module is about ~5 feet away from the bed, so the camera can study the user's whole body posture. The wearable device should be worn by the user while sleeping so the sensors can analyze movements and track the user's sleep.

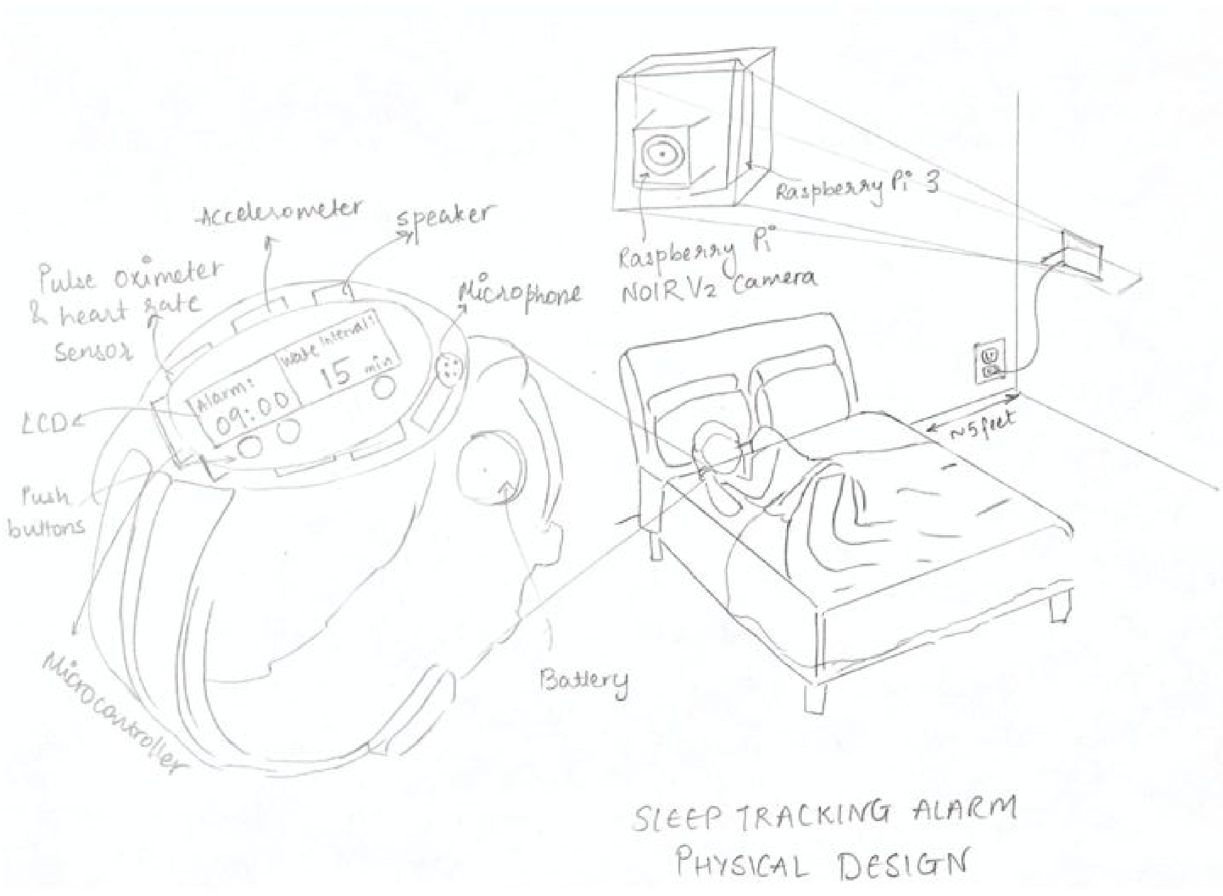

Figure 2. Physical Design of Sleep Tracking Alarm; highlighting the Wearable device and Computer Vision module.

2.3 Wrist-Wearable Device

The Wrist-wearable Device is a system consisting of multiple hardware components. It includes two sensors; a Pulse Oximeter/Heart rate sensor and an Accelerometer, a microphone, a speaker, an LCD display, two pushbuttons, a microcontroller, and lastly, the power supply for each component. This device is intended to be worn by the user while sleeping to collect sensory sleep data, which is used to decide an optimal time to wake up the user based on their set interval, that is, during a period of light sleep. It will also communicate with the Computer Vision module (Raspberry Pi) to disable the alarm. Just like breathing, heart rate and blood pressure vary during sleep. During a non-REM sleep, heart rate and blood pressure go down and are steadier. However, during a REM sleep, they rise higher. Various sensory inputs are used in the wrist-wearable device to develop a more accurate picture of a user's sleep cycle.

2.3.1 Power Supply

2.3.1.1 Li-ionBattery: We will have one rechargeable 3V Li-ion battery that is used to supply power to each component of the project. Li-ion batteries are a great option for wearables because they are extremely light weight and slim so it would be ideal for our project. *Requirement: The battery must be able to power the system to be able to run microcontroller, sensors, as well as enable alarm at 3V.*

2.3.1.2 Li-ion Charger: Li-ion Charger is used to charge the rechargeable Li-ion battery used in the overall system, so the user is able to manually charge the battery.

Requirement: Li-ion charger should be able to charge each Li-ion battery to 3V.

2.3.1.3 Voltage Regulator: We will use a voltage regulator to regulate the voltage that is sent to different components such as pulse oximeter/heart rate sensor, accelerometer, microphone, speaker, and microcontroller

Requirement 1: Must be able to provide 1.95V-3.6V for the accelerometer.

Requirement 2: Must be able to provide 1.8V-3.3V for heart-rate monitor sensor.

Requirement 3: Must be able to provide 2.2V-3.6V for ESP32 microcontroller.

Requirement 4: Must be able to provide 2.7V-3.6V for microphone.

Requirement 5: Must be able to provide 2.2V-3.6V for ESP32 microcontroller.

Requirement 6: Must be able to provide 3V for the rest of the system.

2.3.2 Pulse Oximeter/Heart Rate Monitor

A sleep study in labs consists of polysomnogram (PSG), involving various sensors and recordings. Pulse Oximeters are an integral part of it and are widely used for simultaneous assessment of haemoglobin oxygen saturation. In other words, as a painless process, it employs light beams through the blood measuring the amount of oxygen saturation levels, and thereby telling the heart rate for understanding sleep stages. For example, today's smart watch technologies such as an Apple Watch use similar technology. We plan to use a low power Sparkfun Pulse Oximeter and Heart Rate Sensor - MAX30101 & MAX32664. MAX30101 works as a sensor by bouncing light off the body surface to detect how much light is absorbed within its photodetectors. Data is then sent to MAX32664, which performs algorithms to determine blood oxygen saturation and heart rate. It works best for our project because it also provides important information regarding the sensor's confidence percentage in its reporting, which makes it more reliable.

Requirement 1: Must be able to get heart rate sensory data to accurately understand the user's sleep stage; very light sleep, normal sleep, or deep sleep.

2.3.3 Accelerometer

Accelerometer is the most common in wrist-worn applications. It is used to analyze movements in the user's sleep. We plan to use a Triple Axis Accelerometer Breakout MMA8452Q for our wrist-wearable device as it's a capacitive MEMS accelerometer with 12 bits of resolution. Even better, since it has a low power mode for periods of inactivity. It is configurable to generate inertial wake-up interrupt signals.

Requirement 1: Must be able to take real time sensory inputs when supplied with specified voltage of 1.95V-3.6V.

2.3.4 Microphone

Microphone is used as one of the sensory inputs to track a user's sleep. It analyzes the user's movement in their sleep. We plan to use SparkFun Electret Microphone Breakout, which has capability to amplify sounds of voices (eg. snores), claps, etc and it converts sound waves into electrical waves. We would use the ADC converter on ESP32 microcontroller, so it would be good enough for the purpose of our project.

Requirement 1: Must be able to detect sounds when supplied with specified voltage of 2.7V-5.5V.

2.3.5 Speaker

Speaker is used for the alarm sound to wake up the user. We plan to use Sparkfun Thin Speaker - 0.5W, 8Ohm as it's only 40mm in diameter, and 4mm thick, and perfect to be placed on a wrist-wearable.

Requirement 1: Must be able to output alarm sound when supplied with input voltage of ~1.5V.

2.3.6 Microcontroller

Microcontroller acts as a logical component; the brain of our project. We plan to use an ESP32 microcontroller. It is responsible for taking all the sensory inputs such as Pulse Oximeter sensor, Accelerometer, and microphone, processing inputs to get an average for higher accuracy, and finding an optimal wake up time. It is responsible to enable the alarm; trigger the speaker to wake up the user. Additionally, it receives information of the user's body posture from the computer vision module, more specifically Raspberry Pi via inbuilt Bluetooth to disable the alarm.

Requirement 1: Must be able to take sensory inputs and trigger alarm at an optimal time with time precision of hour and minute.

Requirement 2: Must be able to receive feedback from the computer vision module (Raspberry Pi 3), and disable the alarm within 5 seconds.

2.3.7 Push buttons

Push buttons are a way for letting users add their desired wake up time on the wearable device itself. We plan to use three Mini Pushbutton Switches COM-00097. It's a miniature single pole

single throw switch, which is good for clicks on a wearable. Two switches are used to set up alarm time, specifically, one for hour precision and other for minute precision. Third switch is used for wake up interval time, with 15 minute increment, considering the 90 minute sleep cycle.
Requirement 1: Must be able to be momentary clicked incrementing by 15 minutes when rated up to 50mA current.

2.3.8 LCD Display

LCD screen is attached to the wrist-wearable device for users to display their set alarm time, and wake up time interval, which the user feeds in through the push buttons. We plan to use a small I2C LCD which is ideal for displaying text and numbers, and is easily paired with ESP32 microcontroller to support the logic from push buttons to be displayed accurately.
Requirement 1: Must be able to display numbers precisely within 1-2 seconds when a push button is pressed.

2.4 Computer Vision Module

After triggering the alarm from the wrist-wearable device, we want to make sure the user is actually out of the bed. To accomplish that task, we designed the computer vision module, ideally placed approximately 5 feet from the user's bed to record the user's body posture and confirm the user stood out of the bed.

2.4.1 Raspberry Pi 3 Model B:

Raspberry Pi 3 is intended for high performance to run computer vision algorithms on the video captured by its attached camera. Once the alarm is triggered, the microcontroller from the wrist-wearable device communicates with Raspberry Pi 3 using the Bluetooth. Raspberry Pi 3 triggers the attached Raspberry Pi Camera Module NoIR V2 to start recording the user. Recording is used to study the user's body posture to confirm if the user is sleeping, standing or sitting. We conduct the study by using an open source library called 2D Pose Estimation and Action Recognition. Once the user is out of bed, we will use the built-in Bluetooth module of the Raspberry Pi 3 to send that information to the microcontroller in the wearable device, which thereafter would disable the alarm; accomplishing the final task of the device.

Requirement 1: Must be able to take microcontroller input to trigger the camera.

Requirement 2: Must be able to perform 2D Pose Estimation accurately stating the person is sitting, sleeping or standing.

Requirement 3: Must be able to communicate with the microcontroller to give feedback on disabling the alarm within 3 seconds.

2.4.2 Raspberry Pi Camera Module NoIR V2:

We plan to attach a Raspberry Pi Camera Module NoIR V2 which gives us an advantage to capture the user's posture even in the dark with infrared lighting. Raspberry Pi 3 triggers the camera to start recording, as well as stop recording. The camera will be attached on the front side of the computer vision module system.

Requirement: Be able to record surrounding when notified by the Raspberry Pi 3 that is good enough quality of an image that it is properly analyzed by the 2D Pose Estimation software.

2.5 Risk Analysis

The portion of our project that poses the biggest risk to completion would be our Wearable Device module. This is the most important piece of the project because this is where all the sensory inputs are at, and it will be the one to determine when to wake the user up from their sleep. It also is the most complex, since we will need to take in data from these various inputs and be able to recognize what stage of sleep the user is in. This will provide a higher level of accuracy than normal sleeping tracking devices, since we have additional inputs than the existing devices.

For the accelerometer, we need to make sure that it can measure very sensitive movement. The way it does this is by detecting some sort of change in gravity. The sensitivity of an accelerometer is defined by the rate it can convert some change in gravity into some electrical signal. This is usually expressed in mV/g (milliVolts per gram) or sometimes LSB/g (least significant byte per gram) [4]. For someone who is sleeping, we would want to know of very small vibrations, if any at all, so this would require an accelerometer with higher sensitivity.

The microphone will need to be able to pick as little as noises in movement to larger sounds like snoring. Recognizing sounds aids in telling the stage of sleep, but finding a microphone that is sensitive enough to hear lower decibels and frequencies of noise is important. Sound pressure level is a good indicator of this, and how the distance between the noise and microphone affects its sensitivity [5]. When a user is sleeping, there will typically be no other sounds in the room. The microphone will hence be close to any possible sources of sound from the user.

The last crucial piece of this module is the pulse oximeter/heart rate monitor. The user's heart rate also plays an important role during the different sleep stages. The body relaxes and the heart rate drops during the initial cycles of sleep. Once it enters REM, there may be slight jumps in the heart rate due to dreaming, but when a person is in light sleep and almost ready to wake up, their heart rate begins to slowly rise again [6], and this is the pattern we are trying to look for. A person's heart rate can still vary throughout the night and it is tricky to determine the exact stage, so that is why we've added the additional sensor components to help narrow this down.

3 Ethics and Safety

One ethical concern during the development of the project will be to make the wearable both compact and comfortable for the user. We will have to try to find the smallest hardware components that we can and try to arrange them in a manner that will keep it from being bulky. There is also a safety concern that comes with a wearable, which means that we cannot have any possible openings in the hardware that could harm a person while wearing this. These both fall under the IEEE Code of Ethics #1.

Another potential concern that could arise is maintaining a user's privacy. We record a user's sleep cycle and have a computer vision component that looks to see if the user has got out of their bed. Both of these will accumulate data in some manner, but we do not retain any information on our end. We will not keep the user's sleeping data over time, as it is only used on a nightly basis, and will be overwritten with new data each night. The camera from our Computer Vision module will not be active overnight or during the daytime, and it will include a shutter if the user would like to cover the camera at any point they like. It will only begin detection once it receives a signal from the wearable device that the alarm has been triggered. Any images/videos that are taken to detect a person's posture will not be retained either. Both of these cases align with the IEEE Code of Ethics #1 and #9 about protecting the safety and health of users, as well as avoiding malicious practices.

In regards to any potential breaches, we will need to encrypt data stored in both the Wearable Device and Computer Vision modules. The security of our Computer Vision module will be very crucial since we are examining a person's posture by utilizing a camera. As mentioned before, any images that are taken with the camera will be protected and will not be retained in any other way except to detect if a person is up from their bed.

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