Automated Light Sensor and Motion Sensor Augmented Light Therapy Box using IoT: Implementation and Analysis

Megana Boddam
Computing and Software Systems Department
University of Washington, Bothell

Abstract
Seasonal affective disorder, or SAD, is a mental health disorder that affects people during the winter months. One of the most effective therapies for SAD is using a light therapy box. However, low patient compliance affects the effectiveness of the therapy. Current commercially available light therapy box models do not take patient interaction and compliance into consideration. The objective of this paper is to demonstrate the implementation of automating the process of using light therapy boxes and increase interactivity with the therapy. Another objective is to analyze the feasibility of such a project.

Key Words: Internet of Things, AWS, Cloud Computing, Message Queuing Telemetry Transport (MQTT), Microcomputer, Ambient Light Sensor, PIR Motion Sensor, Light Therapy, Season Affective Disorder (SAD), Raspberry Pi

I. Introduction

Seasonal affective disorder, or SAD, is a mental health disorder that affects people in the winter months[1]. A person absorbs very little light during winter, and in some people, this can develop a condition where their brain becomes chemically and structurally imbalanced. In the US alone, SAD affects approximately 5% of the adult population, which is close to 13 million people. Symptoms of SAD include loss of positive emotions and energy, feelings of worthlessness, inability to concentrate, and uncontrollable urges to eat sugar and high-carbohydrate foods. Although they fade with the arrival of spring, SAD can leave a patient suffering from the consequences of experiencing these symptoms. According to a review published in American Family Physician journal, there are probably several different causes of SAD, including changes in the body's natural daily circadian rhythms, in the eyes' sensitivity to light, and in the function of brain chemical messengers like serotonin.[2] Because lack of sunlight contributes to seasonal affective disorder, getting more light is a part of reversing it. Bright light stimulates cells in the retina that connect to the hypothalamus, a part of the brain that helps control circadian rhythms.[3] Activating the hypothalamus at a certain time every day has the benefits of working to restore a normal circadian rhythm. Light therapy entails sitting close to a "light therapy box" for 30 minutes a day, as close to after waking up as possible. A patient needs 10,000 lux of light intensity during this time. This is approximately 100 times brighter than everyday indoor lighting. Despite the regular prescribed schedule of light therapies, adherence and compliance to light therapies treatments is poor. According to research published last year by Professor Faulkner from the University of Manchester, UK, the reasons range from a lack of knowledge about the importance of light to simple forgetfulness.[4] The current commercially available models of light therapy boxes do not take patient interaction and compliance into consideration. Therefore, my project aims to bring the benefits of IoT devices, such as user interactivity, convenience, data manipulation/analysis and data storage, to the light therapy box, making the therapy easily compliable for patients.

II. Related Work

The development of light therapy boxes and treatment for Season Affective Disorder is closely tied with the original description of the syndrome of SAD. Two decades ago, Rosenthal and colleagues described a series of patients with histories of recurrent depressions that developed in the fall or winter and spontaneously remitted during the following spring or summer.[5] The preliminary finds showed that extremely bright artificial light was more effective than dim light in treating SAD. The light also needed to be administered to the patient in a manner that would in a way increase the length of the day (duration of their experience of light). This is also called the photoperiod. They extrapolated specific parameters that affected the light therapy treatment – the intensity, the duration, and the timing in the day of the bright light exposure – designed to lengthen the photoperiod.

Multiple research groups launched clinical trial programs based on this study and extended them to other mental health disorders as well. The result of this explosion of interest in SAD and light therapy treatments has created a very firm body of evidence that light therapy is valid and effective to use in SAD cases.[6] The Society for Light Treatment and Biological Rhythms is an international organization that was created in response, and it sponsors several journals that emphasize phototherapy and biological rhythms. Despite this growth in clinical and research programs, there has remained little recognition and support for light therapy within most of the clinical psychiatric community.[7] Most insurers do not offer reimbursement for light therapy treatment boxes. Most psychiatric residency training programs do not provide clinical training in light therapy, or more broadly phototherapy. Within the last few years, knowledge of SAD and light therapy has significantly improved through empirical studies.[4] However, neither the public health policies nor the knowledge of the public reflect an understanding of SAD and its treatment. One of the secondary aims of this project is to increase the knowledge base of light therapy. This is accomplished through storing the ambient light reading data and the data on usage of the light therapy box (intensity, duration, timings in the day) by the patient.

III. System Model, Problem Statement, Analysis

A. System Model

The key modules of the system can be broken down into two major groups: physical devices and cloud resources. The cloud resources have two further sub-parts, the resource for user input (Elastic Computing Instance - EC2) and the rest of the cloud resources. Within the physical devices group, there are the Raspberry Pi 3B microcontroller, PIR motion sensor, ambient light sensor, and solenoid. The cloud resources include Amazon Web Services (AWS) Internet of Things (IoT) Core, AWS Lambda Functions, AWS S3 Bucket, and AWS Elastic Computing 2 (EC2). Figure 1 shows the relationship between each module of the system.

Raspberry Pi 3B, in figure 2e, is a microcontroller released in 2016 by Raspberry

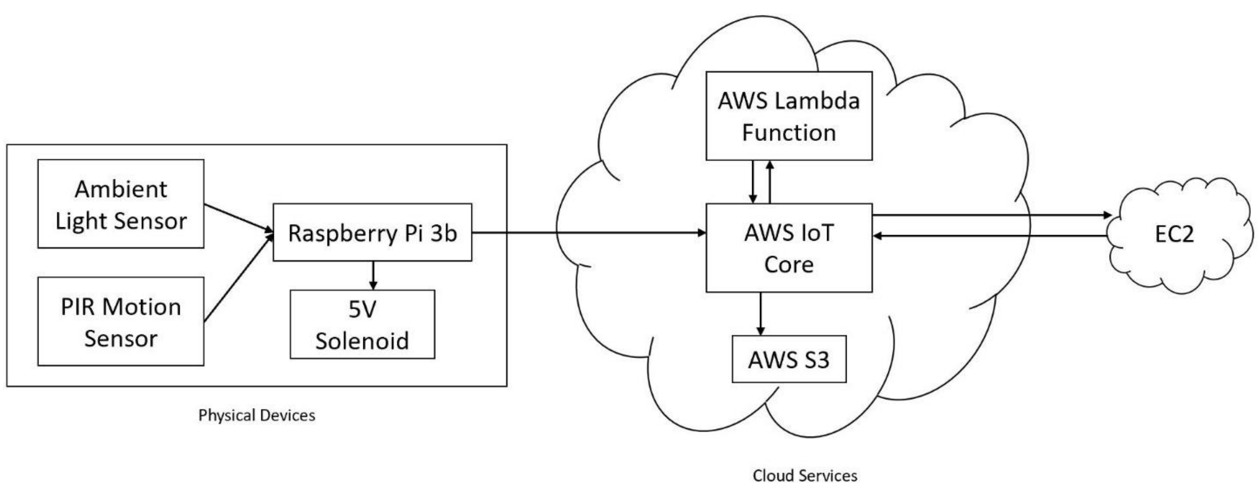

Figure 1: System Architecture

Pi Systems with Wi-Fi and Bluetooth capabilities while maintaining affordability.[8] Fletcher *et. al.* demonstrates in their analysis of Raspberry Pi 3B that it can be successfully used for data collection and distribution between multiple devices via wireless networks.[9] This device has also been chosen because of its affordability and the availability of support and documentation for its use in conjunction with AWS IoT. Raspbian is the software chosen to support the implementation of the Raspberry Pi device as it includes libraries for supporting Raspberry Pi device use and Wi-Fi. Other open-source libraries, such as MQTT Client, will also be used.

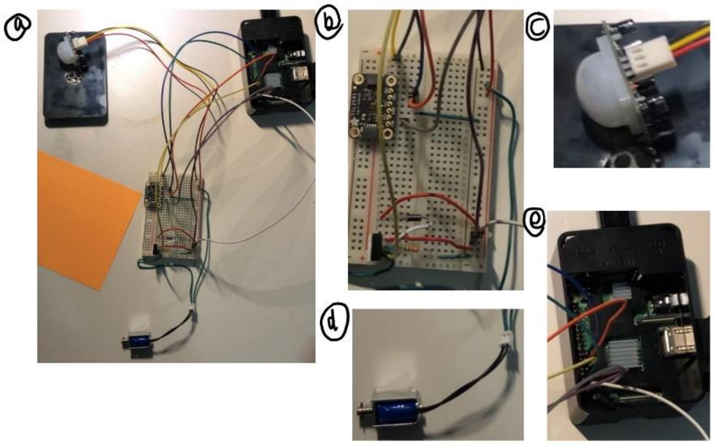

Figure 2: a) is the entire lightSense prototype. b) shows all the connections between the various components, and the ambient light sensor is on the top left of the bread board. c) shows the PIR motion sensor. d) shows the solenoid. e) shows the Raspberry Pi 3b

There are two sensors in the system: the ambient light sensor (figure 2b) and the passive infrared (PIR) motion sensor (figure 2c). The images for these tools are in their respective figures. This ambient light sensor is TSL2591 from Adafruit Industries.[10] It has a very-high dynamic range and sensitivity to visible light, and it also coverts light intensity to a digital signal output. This is possible because it integrates two photodiodes: one broad spectrum and one infrared spectrum. The digital output is then input to the raspberry pi where illuminance in lux is derived. The PIR motion sensor is also from Adafruit Industries.[11] It is made of a pyroelectric sensor, which can detect the levels of infrared radiation from a maximum of 6 meters. Because generally if you are at most 6 meters away from a device, that device is in your sphere of acknowledgement, as 6 meters is half the length of an average room in the US.[12] It is also a relatively inexpensive chip.[13]

There is one actuator for the system: the mini push-pull solenoid (figure 2d) also from Adafruit Industries. It is created of a coil of metal with a rod of metal in the middle.[14] When a voltage is applied to the coil, the rod is pulled to the center of the coil. Then, it can be released by removed the voltage, causing a "push" action. Utilizing this push action, the button on the light therapy box is turned on or off, as the same button is used for both actions on the box. This solenoid was also chosen because of its compactness and affordability.

Looking towards the cloud services, the AWS IoT core is the main hub for this project, facilitating the MQTT communication between the device, lightSense, and the cloud, as well as the data processing and storage. Using the EC2 as a user interface was manageable to attach to the IoT core. The AWS Lambda function is the lynchpin for processing the data. In this implementation, the lambda function has the logical code based on sensor data and user inputs from EC2 to decide when to provide voltage to the solenoid and when not provide it. It also facilitates the storage of data into the S3 bucket. The AWS S3 bucket service provides cloud storage solutions that were used to store and process raw data.

B. Problem Statement and Analysis

The problem being addressed in this project is the difficulty of maintaining a regular light therapy schedule as an individual with little motivation for compliance to the therapy. Lack of interactivity and engagement with the therapy is one of the most common failure points when asking a person to incorporate that therapy into daily life.[15] This project's main purpose is to aid the patient experiencing SAD by reminding them to sit down for their light therapy at their specified times and automatically turning on the therapy box. In future implementations, I would increase the interactivity by providing them statistics about the effects of the therapy on their psych through the ambient light sensor data and quick mood evaluation surveys.

One of the critical assumptions for being able to use this prototype being implemented is access to all the aforementioned devices and software. The cloud resources for this project are all available within the Free Tier of AWS. In addition, I assume that only patients suffering from SAD are interested in this project. It is possible that undergoing light therapy will be beneficial even to people who are suffering from SAD by increasing their baseline performance and mood during winter months. However, without further study and research, which this project could kick-start if it is well received, it would be impossible to claim one way or the other.

IV. Design and Implementation:

A. Physical Devices

To create the prototype, the following list of materials or reasonable substitutes are needed. The suggested vendors for electronic equipment are Adafruit, Arrow Electronics and Chip One Stop Global.

- Ambient Light Sensor
  - High Dynamic Range Digital Light Sensor
  - Chose this because it has the capacity to sense up to 20,000 lux light intensity, and I need light sensors that can approximately sense 10,000 lux because light therapy lamps provide 10,000 lux of light.
- Motion Detector
  - Passive Infrared Motion Sensor
  - I required a motion sensor that can sense living objects within 6m of the sensor.
- Solenoid
  - Adafruit Mini Push-Pull Solenoid - 5V
- Microcontroller with Bluetooth connectivity
  - Raspberry Pi 3 Model B
  - Associated keyboard, mouse, display, power supply, SD card with Noobs (Raspian) software
- MOSFET transistor
- 10k Ohm resistor
- Diode rectifier
- Breadboard and wires (various types such as female-to-male and female-to-female jumper wires)
- Access to following software packages
  - Python 3.7
  - AWS Greengrass and IoT
  - AWS Lambda functions
  - AWS Elastic Computing 2 (EC2)
  - NOOBS (Raspbian)
- Auxiliary materials – not needed but would add value to prototype
  - Light therapy box (my reason for not purchasing this item was a constrained budget)

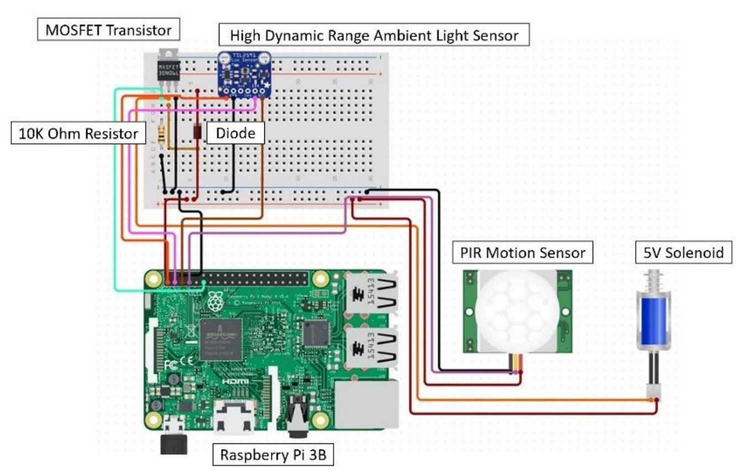

Figure 3: Hardware Electrical Wiring Diagram

The method to connect all the various devices to each other via the breadboard is shown in figure 3. It is important to make sure that the ambient light sensor is soldered to the associated pins. The electrical connectivity will be very poor if the soldering is not performed: the current will have difficulties flowing through the sensor very second and one may need to constantly check whether the sensor is turned on very few minutes. All the components can work with less than 5V of voltage power. So, the implementation will not use too much electricity. It is also important to establish breaks between uses of the solenoid. It is possible for the solenoid to overheat and increase the likelihood of the springs attached it malfunctioning.

The raspberry pi has a program downloaded to it for implementing the functionality of the microcontroller. This includes the authentication information needed to access the AWS cloud services. The obtain the sensor data and output the voltage data appropriately, the input and out pins are hard coding in this program. The collection of data and information of whether solenoid is turned on or pushed out is continuously. The ambient sensor readings are taken each minute with a sample size of 20 to improve the accuracy of the readings. The PIR motion sensor readings are also taken every minute with a sample size of 10 because this sensor has a smaller error range and is very accurate on the presence or absence of a person. This data is converted to JSON before sending it to the IoT core through the MQTT protocol. The data received on whether to turn on the solenoid is also in JSON format and through the MQTT protocol.

B. Cloud Resources

In the IoT core, the Raspberry Pi is set up as a new Thing, where all the certifications for the MQTT protocol are created. These certificate and key files will be saved to the physical device to be used when connecting the cloud resources to the Raspberry Pi. For the Raspberry Pi's Thing profile, the policies must be modified so the device can subscribe to the topic "lightTherapy" and publish to the topic "lightSense". The Lambda function will include algorithms to calculate the average of 20 light level recordings, the average of 10 motion sensor readings, user preferences for time interval of the therapy, and user preferences for timings of the day for therapy, and then, determine whether to publish a message to the "lightTherapy" topic to trigger the solenoid. To allow the Lambda function to publish a message to the topic, the Role attached to the Lambda function includes a IoTPublishPolicy. In addition, one of the algorithms in the Lambda function will also hold the functioning to store the collected data into an S3 bucket. The role attached to the specific algorithm of the lambda function must have a S3PutPolicy applied to it for the Lambda function to be able to write to the S3 bucket. In addition, the frequency of writing to the S3 bucket has to be controlled if staying within the allowed bounds of AWS Free Tier. The customization to fit the free tier could be to only store the data when the solenoid is to be triggered.

C. Connecting Cloud Resource and Physical Devices

The certification files and keys created from the previous section should be stored where accessible from the device-level program. To connect the device to the cloud, the device-level program must contain steps to enable connecting to AWS IoT, publishing a message, and handling a received message. Next, the client to connect to the AWS IoT endpoint must be created using the MQTTClient library. This step involves the use of the certification files and keys. Once completed, the client will connect to the Raspberry Pi Thing and subscribe to the various topics.

In the code to publish a message, a JSON document must be created so that it can be used to transfer the data using the MQTT protocol. The JSON document will include the sensor data from the light and motion sensor. This is then published using the MQTT Client to the lightSense topic. The code to handle the received message will be triggered when a message is received to the lightSense topic. There will also be a lambda function to gain user input published by the EC2 to the "userInput" topic. It will contain the customizations of "Basic", "Timed" or "HandsOff" modes. The "Timed" mode required the inclusion of a number in the JSON object that denotes the duration of the light therapy in minutes. The "HandsOff" mode also requires this. In addition, it requires two strings that each indicate at what time interval of the day it is appropriate to start the therapy and by what time the therapy should end. These strings must be in the format "hh:mm:ss" of a 24 hour clock. The MQTT topics used in this prototype are lightSense, lightTherapy, and userInput.

On the cloud services side, there need to be two rules using AWS IoT to direct messages received to their intended destinations. The first rule needs to direct all incoming data messages received by the lightSense topic to the Lambda function. The next rule directs all messages received by the userInput topic to be directed to another specific Lambda function.

V. Evaluation

To evaluate the efficiency and the security of this system, the following experiments and research were conducted. To assess the efficiency of the system, time elapse measurements were taken between two events. 20 trials were conducted to measure the time interval between acquiring an ambient light reading of less than 4000 lux and subsequent receipt of the signal to trigger the solenoid (figure 4). The mean value for this time interval was 4805.65 milliseconds with a standard deviation of 0.9097 milliseconds. The distribution of this data can be found in figure 4. The same experiment was performed again but with different events. The first event was the detection of motion by the Raspberry Pi and the second event is the receipt of the trigger of the solenoid. Figure 5 shows this data, and the mean time interval is 4604.25 milliseconds with a standard deviation of 0.8874 milliseconds. The last experiment is again a repeat of this technique while considering both the light and motion sensors. The measurement is the time interval between the following two events: the first event is acquiring an indication of low light (< 4000 lux) and the presence of motion by the Raspberry Pi; the second event is the receipt of indication to trigger the solenoid. The data is shown in figure 6, and the mean time interval is 5249.75 milliseconds with a standard deviation of 1.259 milliseconds. These metrics show that the elapsed time between various necessary triggering events is very short, on the order of seconds, and the conclusion of efficacy of this type of solution and this prototype is plausible.

To evaluate the security of the system, more research was done on whether the Raspberry Pi as a device had a possible risk of unauthorized access to its transmitted data. It has been shown in multiple studies that it is possible to hack into Raspberry Pi with a basic knowledge of wireless sensor networks.[16] It is possible for fake data to be pushed into the network. Because this is a prototype/device that is related to a person's mental health condition, making it as secure as possible in the final iteration is paramount. Reliability is also an important aspect of a secure network, so the use of Transmission Control Protocol (TCP) is also recommended over User Datagram Protocol (UDP).

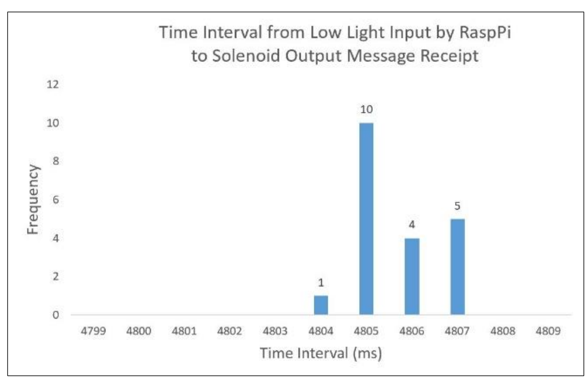

Figure 4

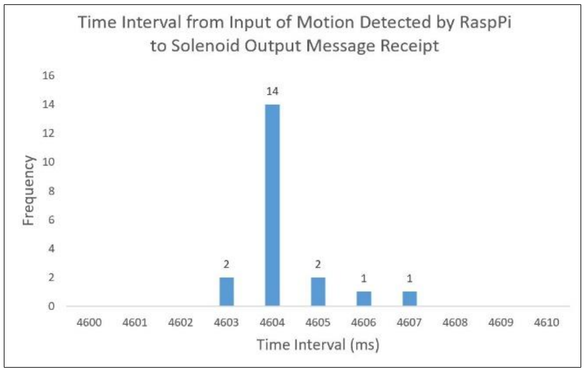

Figure 5

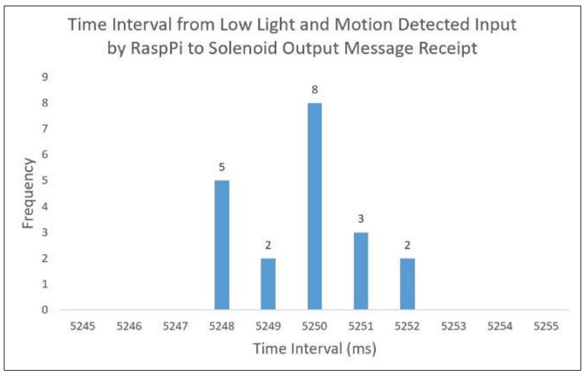

Figure 6

VI. Conclusion and Future Work

The purpose of this project was to implement the automation of using light therapy boxes and increase interactivity with the therapy. The prototype created, lightSense, accomplishes this through sensing human motion and ambient light intensities around the light therapy box, and automatically turning the light therapy on or off. Because of the automatic reminder of the need to undergo therapy and detection of whether the therapy had been received or not, the goals of increasing compliance with the therapy were accomplished. The prototype is also economically and technically feasible, as observed in sections IV and V of this paper. However, we have not increased interactivity with the therapy to appreciable amounts. It is increased a little because of the prototype's need for an initial configuration between Basic, Timed and Hands-off modes; however, further interaction includes simple messages sent to the user. All the ambient light data and therapy interval data is stored in AWS cloud. Therefore, future work to improve the prototype would include utilizing this data to provide infographics to the user. Moreover, creation of mini surveys aimed to analyze the mood and energy levels of the user would also be beneficial. They would provide us with numerical data to show the user the effectiveness of the light therapy boxes.

VII. Citation

[1] Torres, F. (2020, October). Seasonal affective disorder (SAD). American Psychiatric Association. Retrieved November 2, 2021, from https://www.psychiatry.org/patients-families/depression/seasonal-affective-disorder.

[2] Melrose S. (2015). Seasonal Affective Disorder: An Overview of Assessment and Treatment Approaches. Depression research and treatment, 2015, 178564. https://doi.org/10.1155/2015/178564

[3] Pjrek E, Friedrich ME, Cambioli L, Dold M, Jäger F, Komorowski A, Lanzenberger R, Kasper S, Winkler D. The Efficacy of Light Therapy in the Treatment of Seasonal Affective Disorder: A Meta-Analysis of Randomized Controlled Trials. Psychother Psychosom. 2020;89(1):17-24. doi: 10.1159/000502891. Epub 2019 Oct 1. PMID: 31574513.

[4] Faulkner, S. M., Dijk, D.-J., Drake, R. J., & Bee, P. E. (2020, March 12). Adherence and acceptability of light therapies to improve sleep in intrinsic circadian rhythm sleep disorders and neuropsychiatric illness: A systematic review. Sleep health. Retrieved November 3, 2021, from https://pubmed.ncbi.nlm.nih.gov/32173374/.

[5] Rosenthal NE, Sack DA, Gillin JC, Lewy AJ, Goodwin FK, Davenport Y, Mueller PS, Newsome DA, Wehr TA: Seasonal affective disorder: a description of the syndrome and preliminary findings with light therapy. Arch Gen Psychiatry 1984; 41:72–80.

[6] Terman M, Boulos Z, Campbell SS, Dijk D-J, Estman CI, Lewy AJ: Light treatment for sleep disorders: ASDA/SLTBR Joint Task Force Consensus Report. J Biol Rhythms 1995; 10:101–176

[7] Wirz-Justice A: Beginning to see the light. Arch Gen Psychiatry 1998; 55:861–862.

[8] A raspberry pi 3 model B. Raspberry Pi. (n.d.). Retrieved December 12, 2021, from https://www.raspberrypi.com/products/raspberry-pi-3-model-b/.

[9] Fletcher, A. C., & Mura, C. (n.d.). Ten quick tips for using a raspberry pi. PLOS Computational Biology. Retrieved December 12, 2021, from https://doi.org/10.1371/journal.pcbi.1006959.

[10] ams AG. (n.d.). *TSL2591 - Adafruit Industries*. TSL2591 Light-to-Digital Converter. Retrieved December 12, 2021, from https://cdn-learn.adafruit.com/assets/assets/000/078/658/original/TSL2591_DS000338_6-00.pdf?1564168468.

[11] Ada, L. (n.d.). Pir motion sensor. Adafruit Learning System. Retrieved December 12, 2021, from https://learn.adafruit.com/pir-passive-infrared-proximity-motion-sensor.

[12] Stewart, J. (2017, January 17). Average bedroom size and dimensions. Doorways Magazine. Retrieved December 12, 2021, from https://www.doorwaysmagazine.com/average-bedroom-size/.

[13] Ada, L. (n.d.). Pir motion sensor. Adafruit Learning System. Retrieved December 12, 2021, from https://learn.adafruit.com/pir-passive-infrared-proximity-motion-sensor.

[14] Adafruit Industries. (n.d.). Mini push-pull solenoid - 5V. Retrieved December 12, 2021, from https://www.adafruit.com/product/2776.

[15] Faulkner, S. M., Dijk, D.-J., Drake, R. J., & Bee, P. E. (2020, March 12). Adherence and acceptability of light therapies to improve sleep in intrinsic circadian rhythm sleep disorders and neuropsychiatric illness: A systematic review. Sleep health. Retrieved November 3, 2021, from https://pubmed.ncbi.nlm.nih.gov/32173374/.

[16] M. Yevdokymenko, E. Mohamed and P. Onwuakpa, "Ethical hacking and penetration testing using raspberry PI," 2017 4th International Scientific-Practical Conference Problems of Infocommunications. Science and Technology (PIC S&T), 2017, pp. 179-181, doi: 10.1109/INFOCOMMST.2017.8246375.