IoT based Circadian Rhythm Monitoring using Fuzzy Logic

K. Sornalakshmi, Revathi Venkataraman, N. Parthiban and V. Kavitha
Department of Computer Science and Engineering, SRM Institute of Science and Technology, Kattankulathur, Tamilnadu, India

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Abstract: A healthy body and happy mind is essential to lead a successful life. For the betterment of health, it is important to develop positive health habits. The human body has a 24-hour internal clock called circadian rhythm that can be affected by our lifestyle. It is a natural intelligence of the human body to perform certain tasks including hormone secretion, memory functions, immune system functions, etc. during certain periods of the day. This rhythm is synchronized with the light and dark cycle of the environment. However, when there are variations in light, sleeping at unusual times, exposure to bright lights at night and traveling across time zones, certain functions of the body may get activated and deactivated at inappropriate times. With smart devices, the Internet of Things (IoT) has a great impact on our everyday lives. Healthcare IoT systems use the data provided by the IoT devices to make automated decisions or to provide recommendations to users. This work is concerned with a health IoT system consisting of different IoT devices used by users who want to know about their circadian rhythms. In addition to this, fuzzy logic has been used to evaluate the circadian rhythm based on the effects of the time at which an individual starts to sleep, wake up time and mobile light exposure time. It classifies the circadian rhythm as aligned, intermediate and disrupted.

1 INTRODUCTION

In modern working culture, with the opportunity to work from anywhere at any time, many of us forgot to keep our internal circadian rhythm regularised. Circadian rhythms are 24-hour cycles in our body's internal clock to perform certain tasks during certain times of the day using an intelligence that nature has designed for us. It plays a key role in regulating our metabolism, hormone production, cell growth and many activities. Living with the lifestyle against circadian rhythm has a high impact on health in such a way that increases risk of obesity, metabolic syndrome, and cardiovascular diseases (Kessler and Pivovarova, 2019). It is vital to understand the impact of circadian disruption on human health and align them to improve the quality of our health and life on earth (Walker et al., 2020). Almost all functions of the body depend upon the circadian clock which operates with the light and darkness cycle. While the other cues like social activity, feeding and fasting cycle, nutritional factors also influence the circadian rhythm. From this perspective, an understanding about the circadian clock and how the accurate timing of every activity in our lifestyle will help to shed light on our health (Alemdar, 2018). Lifestyle aligning with the laws of nature regulates the circadian rhythm to prevent health illness. There are a number of health habits that can support us to live in synchronize with the circadian rhythm. Lifestyle changes that honour our body's natural schedule will help to improve health, disease prevention and more.

The light/dark cycle of nature is the best known regulator of the circadian clock (Fukuda and Morita, 2017). Other than natural light, humans are exposed to artificial lighting from electronic screens on televisions, computers, tablets, and cell phones. The impact of light on the circadian rhythm depend upon the intensity and timing of exposure to light (Blume et al., 2019). Environment temperature seems to play a big part in the circadian system. The clock neurons get the temperature information from external thermoreceptors which are specialized neurons used by the skin to detect changes in temperature (Yadlapalli et al., 2018). Environmental factors disorganise the circadian system, and thereby adversely affect the health. Since there is an interaction between the circadian rhythm and metabolism, timing of food intake is a crucial factor to regulate metabolism (Jennifer et al., 2019).

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Changes in the core body temperature and skin temperature reflect the circadian disruption. Nutritional compounds have robust effects on the circadian system. To maintain the circadian rhythm, the choice of the nutrition should be clean and healthy. The misaligned circadian cycle leads to emotional instability and also results in mood disorders such as depression, anxiety and bipolar disorder (McClung, 2013). Light and dark cycles play a central role in the regulation of the body's internal clock that affects the secretion of melatonin which is an essential hormone for promoting sleep. The melatonin suppression and circadian disruption are modulated by the amount of light seen during the day. Also, the effect of light on the circadian rhythm mainly depends on the duration, timing and intensity of light exposure (Papatsimpa et al., 2020). Today, because of the technological addiction and the overuse of computers, laptops, and smartphones, people are increasingly exposed to artificial light which develops sleep deprivation (Lee and Kim, 2019). The circadian system is most sensitive to light-induced delays particularly in the evening hours. In our proposed work, the circadian rhythm of an individual is classified using the fuzzy model with the input parameters sleep, wake up and light exposure time.

The rest of the paper is organized as follows. Section 2 discusses the role of the internet of things in circadian rhythm. The proposed fuzzy model is presented in Section 3. Section 4 gives the analysis of the proposed model with its results. The conclusion and the future work is presented in Section 5.

2 INTERNET OF THINGS IN CIRCADIAN RHYTHM

The study conducted in (Roomkham et al., 2019) to investigate the possibility of using an Apple watch for sleep monitoring recommends that Apple watch could be best in detecting sleep and wakefulness as it has high accuracy (97%) and sensitivity (99%). Apple Watch consists of a triaxial accelerometer and heart rate sensors to measure sleep/wake up cycle. Hence, we used that Smart watch to measure input parameters X_1 and X_2. Exposure to artificial light is mentioned in suppressing Melatonin, which is a hormone inducing sleep, causing sleep disorders by disrupting our natural circadian rhythms. To measure the third input parameter, mobile light exposure time, Apple iPhone was used. This smartphone will send the overall mobile usage time of the particular user to the cloud. We recorded 30 days of sleep/wake up and mobile light exposure data from 15 healthy adults (10 female and 5 male) using their smart devices such as Apple Watch and Apple iPhone. The participants involved in this study were morning type. They used to have normal hours of work from 9.00 A.M. to 5.00 P.M.

3 FUZZY MODEL FOR CIRCADIAN RHYTHM CLASSIFICATION

For the present study, wearable technology has been used to calculate sleep/wake up schedule and light exposure. To measure the output Circadian Rhythm (Z), Sleep Time (X_1), Wake up Time (X_2), Light Exposure Time (X_3) are considered as input parameters.

Mamdani fuzzy rules have been used for building a fuzzy model. It is of the form in Equation 1.

$$IF\ X\ is\ I\ THEN\ Y\ is\ J \tag{1}$$

The general form of the rule is shown in Equation 2.

$$\begin{gathered} IF\ X_1\ is\ I_1\ AND\ X_2\ is\ I_2 \ldots X_n \text{ is } I_n \text{ THEN } \ldots Y_1 \text{ is} \\ AND\ Y_2\ is\ J_2 \ldots Y_n \text{ is } J_n \end{gathered} \tag{2}$$

We assume a Gaussian membership function that is defined by a mean m and a standard deviation $\sigma > 0$. The fuzzy membership value is computed using the following Equation 3.

$$y = gaussmf(x, params) \tag{3}$$

Where x represents the input values for which membership values to be computed and $params$ represents membership function parameters, which specified as the vector (σ, c), where σ represents standard deviation and c represents the mean. $gaussmf()$ computes fuzzy membership value y using the Gaussian membership function shown in Equation 4.

$$f(x; \sigma, c) = e^{\frac{-(x-c)^2}{2\sigma^2}} \tag{4}$$

The membership values are calculated for each input value in x. The general representation of the fuzzy system is depicted in Figure 1.

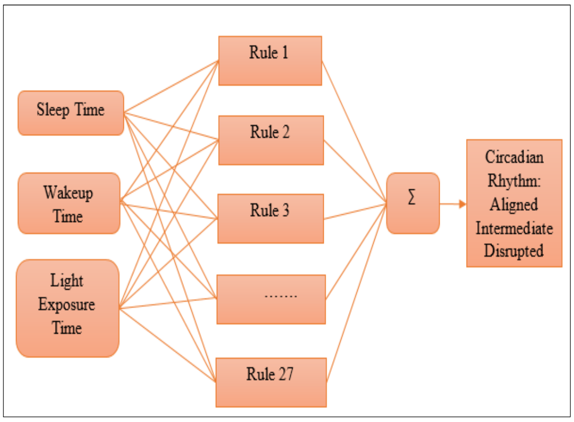


Figure 1: General representation of the fuzzy system.

The first input parameter (X_1) describes the time at which individuals start to sleep and it is mapped to a scale varying from 0 to 10. Highest score implies regular and consistent sleep time. The qualitative descriptors of X_1 shown in Figure 2 are categorized as 'Correct', 'Moderate' and 'Late'.

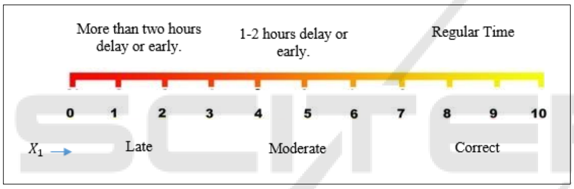


Figure 2: Qualitative descriptors of Sleep Time (X_1).

The second input parameter (X_2) describes the time at which an individual wakes up and it is also mapped to a scale varying from 0 to 10 as shown in Figure 3. Highest score indicates regular wake up time and the lowest score indicates delayed or early wake up time.

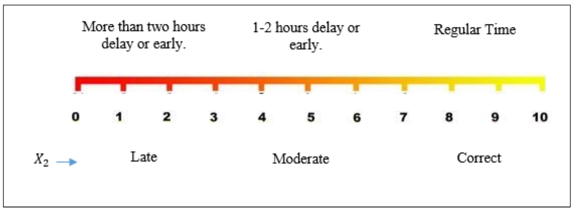


Figure 3: Qualitative descriptors of Wake up Time (X_2).

The input parameter (X_3) defines the artificial blue light exposure duration of an individual. Scale between 0 and 10 has been used to classify this input. Light exposure in the late evening and early night i.e., the hours surrounding the individual's typical bedtime produces shifts in the circadian system and also light exposure in the late night and early morning produces shifts in the circadian system (Zisapel, 2001). From this inference, the highest score has been assigned to limited exposure to artificial blue light and the lowest score has been assigned to over exposure to light. The qualitative descriptors of input X_3 shown in Figure 4 are categorized as 'Limited', 'Moderate' and 'Over'.

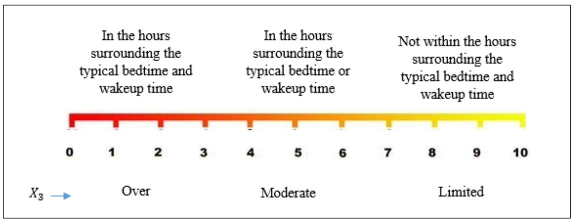


Figure 4: Qualitative descriptors of Light Exposure Time.

The qualitative descriptors of the circadian rhythm (Z) presented in Figure 5 are categorized as 'Aligned (A)', Intermediate (I)', and 'Disrupted (D)'. The inference from (Guo et al., 2020) and the inference from the dataset (Rossi et al., 2020) was used to classify the circadian rhythm. In their work, the authors have presented an open dataset of Psycho-Physiological responses of younger adults. They have considered many parameters which include sleep/wakeup data and small/large screen usage time. In our work, we have considered this dataset as a reference to classify the circadian rhythm.

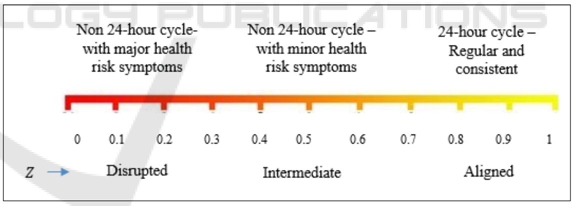
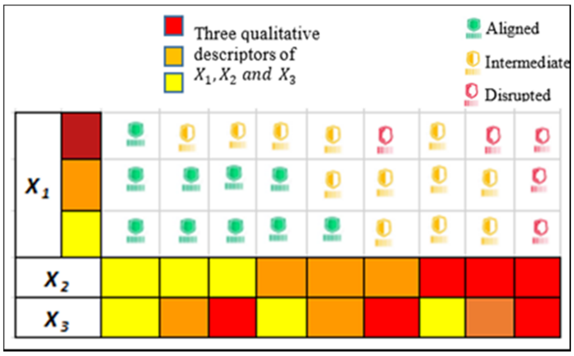


Figure 5: Qualitative descriptors of Circadian Rhythm (Z).

The circadian rhythm score is specified in a way that 0 indicates the lowest score, whereas 1 indicates the highest score. Gaussian membership functions have been used to describe the Circadian Rhythm score. Since, three input parameters each with three membership functions are used to determine the circadian rhythm score, 27 if-then rules have been framed for this study. For example, the first rule has been created as shown in Equation 5.

$$\begin{gathered} IF\ X_1 = 10\ and\ X_2 = 10\ and\ X_3 = 10, \\ then\ Z\ is\ Aligned \end{gathered} \tag{5}$$

Correspondingly, remaining rules are framed by taking into account all other possible combinations.



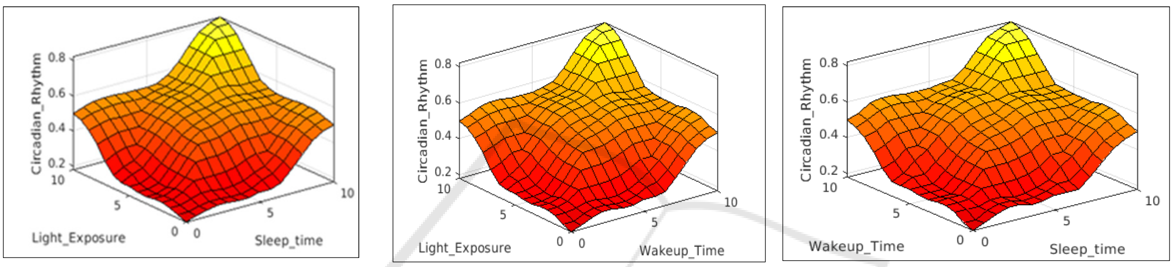
X_1	🟥	🟢	🟡	🟡	🟡	🟡	🔴	🟡	🔴	🔴
	🟧	🟢	🟢	🟢	🟢	🟡	🟡	🟡	🟡	🔴
	🟨	🟢	🟢	🟢	🟢	🟢	🟡	🟡	🟡	🔴
X_2		🟨	🟨	🟨	🟧	🟧	🟧	🟥	🟥	🟥
X_3		🟨	🟧	🟥	🟨	🟧	🟥	🟨	🟧	🟥

Figure 6: Fuzzy Rule Base.

The total number of rules that completely define the fuzzy set is 27 and it is depicted in Figure 6.

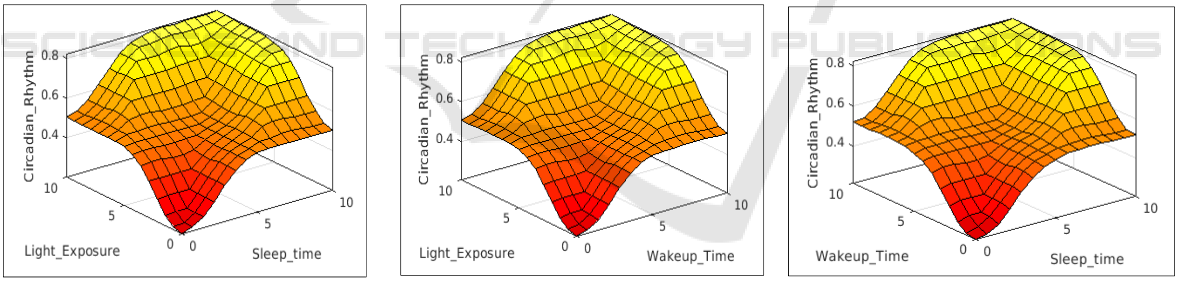
4 ANALYSIS

From Figure 7.A, it can be inferred that the circadian rhythm of an individual falls low when the time to start sleep is late and when they are over exposed to light. For example, the circadian rhythm falls below 0.2 (i.e. Disrupted) when the sleep time is around 3 (i.e. Late) and the light exposure is around 3 (i.e. Over exposure). From Figure 7 .B, it can be inferred that the circadian rhythm of an individual falls low when the time to wake up is late and when they are over exposed to light. For example, the circadian rhythm falls below 0.2 (i.e. Disrupted) when the wake up time is around 3 (i.e. Late) and the light exposure is around 3 (i.e. Over Exposure).



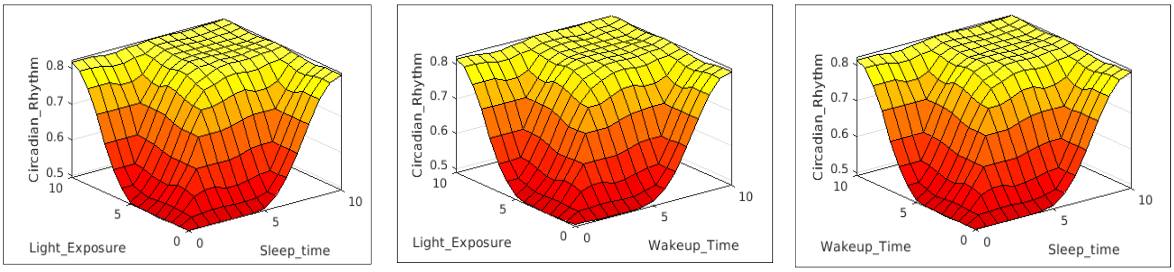
(a) (b) (c)

Figure 7: Relationship between inputs and outputs for disrupted circadian rhythm. Output: Circadian Rhythm and inputs: A: Sleep Time and Light Exposure, B: Wake up Time and Light Exposure and C: Sleep Time and Wake up Time.



(a) (b) (c)

Figure 8: Relationship between inputs and outputs for Intermediate circadian rhythm. Output: Circadian Rhythm and inputs: A: Sleep Time and Light Exposure, B: Wake up Time and Light Exposure and C: Sleep Time and Wake up Time.



(a) (b) (c)

Figure 9: Relationship between inputs and outputs for aligned circadian rhythm. Output: Circadian Rhythm and inputs: A: Sleep Time and Light Exposure, B: Wake up Time and Light Exposure and C: Sleep Time and Wake up Time.

From Figure 7.C, it can be inferred that the circadian rhythm of an individual falls low when the time to start sleep is late and when the time to wake up is late. For example, the circadian rhythm falls below 0.2 (i.e. Disrupted) when the sleep time is around 3 (i.e. Late) and the wake up time is around 3 (i.e. Late).

From Figure 8.A, it can be concluded that when the time to start sleep is moderate (in between correct and late) and also when they are moderately exposed to light, an individual's circadian rhythm falls intermediately. For example, the circadian rhythm lies at 0.5 (i.e. Intermediate) when the sleep time is around 5 (i.e. Moderate) and the light exposure is around 6 (i.e. Moderate). From Figure 8.B, it can be inferred that the circadian rhythm of an individual falls intermediately when the time to wake up is moderate and when they are moderately exposed to light. For example, the circadian rhythm lies at 0.5 (i.e. Intermediate) when the wake up time is around 5 (i.e. Moderate) and the light exposure is around 6 (i.e. Moderate). From Figure 8.C, it can be inferred that the circadian rhythm of an individual falls intermediately when both the time to start sleep and wake up is moderate. For example, the circadian rhythm falls lies at 0.5 (i.e. Intermediate) when the sleep time is around 5 (i.e. Moderate) and the wake up time is around 6 (i.e. Moderate).

From Figure 9.A, it can be inferred that the circadian rhythm of an individual becomes high when the time to start sleep is correct and when they have limited light exposure. For example, the circadian rhythm becomes 0.8 (i.e. Aligned) when the sleep time is around 9 (i.e. Correct) and the light exposure is around 9 (i.e. Limited exposure). From Figure 9.B, it can be inferred that the circadian rhythm of an individual becomes high when the time to wake up is correct and when they have limited light exposure. For example, the circadian rhythm becomes 0.8 (i.e. Aligned) when the wake up time is around 9 (i.e. Correct) and the light exposure is around 9 (i.e. Limited exposure). From Figure 9.C, it can be inferred that the circadian rhythm of an individual becomes high when both the time to start sleep and wake up is correct. For example, sleep and wake up is correct. For example, the circadian rhythm becomes greater than 0.8 (i.e. Aligned) when the sleep time is around 9 (i.e. Correct) and the wake up time is around 9 (i.e. Correct).

5 CONCLUSION

The contributions of this work are the ability to evaluate and classify the circadian rhythm of an individual to improve their health. This classification has been done using the input parameters, the time at which individuals start to sleep, wake up time and light exposure time. A fuzzy logic system for the evaluation of an individual's circadian rhythm has been developed. This evaluation will be useful for the early diagnosis of circadian rhythm disruption. In future work, the accuracy of the fuzzy model will be validated with the results classified by the medical experts. Future work includes other factors that influence the circadian rhythm such as eating, exercise for assessment and also inputs will be gathered from individuals by using wearable devices with capacities of measurement of physiological parameters. The trust value of the source will be taken into account in future.

REFERENCES

Kessler, K., & Pivovarova-Ramich, O. (2019). Meal timing, aging, and metabolic health. International journal of molecular sciences, 20(8), 1911.

Walker, W. H., Walton, J. C., DeVries, A. C., & Nelson, R. J. (2020). Circadian rhythm disruption and mental health. Translational psychiatry, 10(1), 1-13.

Alemdar, E. (2018). External factors that direct the biological clock and role in treatment of disease. Arch Med Vol, (10).

Fukuda, Y., & Morita, T. (2017). Effects of the light–dark cycle on diurnal rhythms of diet-induced thermogenesis in humans. Chronobiology international, 34(10), 1465-1472.

Blume, C., Garbazza, C., & Spitschan, M. (2019). Effects of light on human circadian rhythms, sleep and mood. Somnologie, 23(3), 147-156.

Yadlapalli, S., Jiang, C., Bahle, A., Reddy, P., Meyhofer, E., & Shafer, O. T. (2018). Circadian clock neurons constantly monitor environmental temperature to set sleep timing. Nature, 555(7694), 98-102.

Jennifer, L.K., Sharon V.T., & Hannah, D.H. (2017). Complex interactions of circadian rhythms, eating behaviors, and the gastrointestinal microbiota and their potential impact on health, Nutrition Reviews, 75(9), 673-682.

McClung, C. A. (2013). How might circadian rhythms control mood? Let me count the ways... Biological psychiatry, 74(4), 242-249.

Papatsimpa, C., Bonarius, J. H., & Linnartz, J. P. M. G. (2020, June). Human Centric IoT Lighting Control based on Personalized Biological Clock Estimations. In 2020 IEEE 6th World Forum on Internet of Things (WF-IoT) (pp. 1-6). IEEE.

Lee, E., & Kim, M. (2019). Light and life at night as circadian rhythm disruptors. Chronobiology in Medicine, 1(3), 95-102.

Roomkham, S., Hittle, M., Cheung, J., Lovell, D., Mignot, E., & Perrin, D. (2019). Sleep monitoring with the Apple Watch: comparison to a clinically validated actigraph. F1000Research, 8(754), 754.

Zisapel, N. (2001). Circadian rhythm sleep disorders. CNS drugs, 15(4), 311-328.

Guo, J. H., Ma, X. H., Ma, H., Zhang, Y., Tian, Z. Q., Wang, X., & Shao, Y. C. (2020). Circadian misalignment on submarines and other non-24-h environments–from research to application. Military Medical Research, 7(1), 1-12.

Rossi, A., Da Pozzo, E., Menicagli, D., Tremolanti, C., Priami, C., Sîrbu, A.... & Morelli, D. (2020). A Public Dataset of 24-h Multi-Levels Psycho-Physiological Responses in Young Healthy Adults. Data, 5(4), 91.