Fuzzy Wake-up System

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Abstract

We present a novel wake-up system, which uses fuzzy logic to process inputs provided by various Internet of Things applications to determine the wake-up time, volume of alarm, and strongness of coffee in order to guarantee maximum alertness at the start of the day.

1 Introduction

Even though we spend about a fourth of our lives sleeping, sleep still remains a mystery. With career and private life demanding increasing amounts of time, reducing sleep seems like an evident solution. Research has shown, though, that even minimal sleep loss has significant negative consequences on mood, energy, and stress handling ability (Pilcher and Huffcutt 1996). In today's fast-paced society, a healthy amount of sleep remains one of the few constants that cannot be compromised. Guaranteeing a good night's sleep thus becomes one of the top priorities.
Whereas human beings have relied for most of their history on their own circadian rhythms to wake up, the eventful life of today's professionals necessitates the use of a dedicated system. Current alarm clocks, however, frequently are obnoxious and fail to adapt to changing circumstances of sleep, which is dependent on a multitude of factors. With the advent of the Internet of Things, for the first time we have the means on our hands to actually measure these factors.
We propose a fuzzy wake-up system that leverages inputs from connected devices in order to guarantee maximum alertness in the morning in any situation.

2 Background

Sleep consists of rapid eye movement (REM) and non-REM (NREM) sleep. After going to bed, one typically goes through two phases of light NREM sleep and one of deep NREM sleep. It is in the latter that the body regenerates. This phase is followed by REM sleep, which is associated with dreaming. Remarkably, the exact function of REM sleep still remains a mystery and is a source of controversies.
These sleep cycles repeat throughout the night. Waking up in the deep NREM or REM sleep phase should be avoided, as it can cause severe disorientation. If it can't be helped, because you have you went to bed late and have an early meeting, then our system aims to make you as awake as possible in the first morning hours.
To maximize alertness and responsiveness in the morning, our system not only determines the ideal time of alarm, but also determines the volume of alarm and the strongness of the coffee. We considered different options for a morning energy boost (e.g. tea, yoga, an apple, running) but opted for coffee as it heightens awakeness for the first two hours after coffee consumption (Reyern and Horne 2000), (Gary H. Kamimori 2005), and already is the go-to solution for the majority of the population (Live Science 2014).
Among the factors, which have been found to influence sleep, none are crisp or completely understood. Most of them rather serve as rules-of-thumb guiding best sleeping practices, i.e. "sleep in a quiet, dark environment". Furthermore, a wake-up system needs to be able to adapt to changing parameters. These premises have motivated our decision to employ fuzzy logic, as it offers a robust way to deal with these uncertain concepts.
There are two types of fuzzy logic systems: Mamdani and Takagi-Sugeno. The latter is extremely fast due its mathematical simplicity, which makes it the go-to choice for real-time systems. As our system possesses almost all of its inputs at the time of going to sleep, it has several hours to perform computatations. We have thus opted to use Mamdani for our system due to its superior preciseness.

3 Simulation/Model

Sleep is very complex, being dependent on a plethora of different factors. To be able to incorporate as many as possible without losing the intuitiveness of fuzzy logic, we decided to split up our system in three related but semantically distinct subsystems.

In total, our three subsystems take seven distinct input parameters, which are then mapped to one intermediate and three final output values, as can be seen in figure 1.

Fuzzification

Subsystem 1: Easiness of falling asleep Our first subsystem measures how easy it is to fall asleep. It takes the following three inputs (note: linguistic terms are put in parentheses after the parameters):

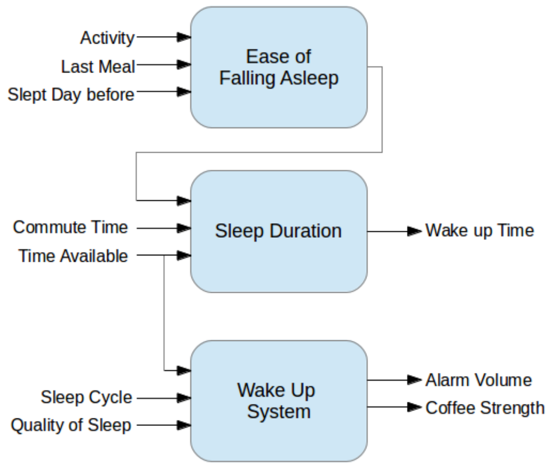

Figure 1: Architecture of the system

- **Last meal or drink** (*Just Now, Some Time Ago, Long Time Ago*): The number of minutes (0-300) elapsed from the last consumption of a meal or beverage until the time of falling asleep. The membership function is based on data from Joy Bauer's article "How Food Affects".
- **Slept day before** (*Little, Normal, A Lot*): The number of minutes (0-720) of sleep on the previous day. This number is taken from the log of the previous day.
- **Activity during day** (*Little, Normal, A Lot*): The number of calories burnt (0-3000) during the day. This number is taken from a wearable or activity tracker, or – in lack of the former – assumes the default amount of calories burnt depending on the profession.

From these inputs, it then computes the **easiness of falling asleep**, a parameter between 0 and 1 measuring how easy it was to fall asleep (0 being very easy), which is then taken as input by the next system.

Subsystem 2: Sleep duration Our second subsystem determines the time of alarm. For this, it takes the following three inputs:

- **Time available to sleep** (*Little, Normal, A Lot*): The number of minutes between going to bed and the time of the first meeting or event on the next day (0-600). This parameter is precomputed by accessing calendar information.
- **Commuting time** (*Short, Normal, Long*): The number of minutes it takes to commute (0-120). This number is taken by accessing the Google Maps API.
- **Easiness of falling asleep** (*Easy, Normal, Hard*): The value (0-1) computed by the first system.

These inputs are used to compute a **sleep duration** modifier, an output value between 0 and 1 that is multiplied with the time available to sleep to compute the actual sleeping time, which can then be added to the time of going to sleep to calculate the time of alarm.

Subsystem 3: Easiness of waking up (volume of alarm & coffee) Our third subsystem measures how easy it is to wake up. It is only triggered at the time of alarm as it depends on the sleep cycle at that moment. It takes the following three parameters as input:

- **Time available to sleep** (*Little, Normal, A Lot*): A value between 0 and 720. See above.
- **Current sleep cycle** (*Awake, Lightly Asleep, Fast Asleep*): A value between 0 and 1 corresponding to the current sleep cycle, with 0 being awake and 1 being fast asleep. The current sleep cycle can be determined by measuring body movement and observing the sequence of sleep cycles.
- **Quality of sleep** (*Bad, Normal, Good*): A value between 0 and 1 measuring the quality of sleep, with 0 being bad and 1 being good. This value is precomputed by another subsystem, which we have chosen not to design for the sake of conciseness. It depends on the amount of REM sleep, the brightness, and the noise of the bedroom.

From these inputs, the system then computes two output values:

- **Volume of alarm** (*Low, Medium, High*): The volume in decibels (0-100) of the alarm. For reference, nomal conversation is at 60db; alarms on market have a range of up to 113db.
- **Strongness of coffee** (*Weak, Regular, Strong*): The number of table spoons per 6 oz/cup (0-3).

Inference

In total, we required $3 \cdot 3 \cdot 3 + 2 \cdot 3 \cdot 3 \cdot 3 + 3 \cdot 3 \cdot 3 = 108$ rules. While we used the cross-product to compute the rules for subsystem 1 and 3, letting the linguistic terms appear in every combination, subsystem 2 uses the inputs pair-wise. This was done to facilitate the development of the rules. The increased number of rules of subsystem 2 are due to two of the input membership functions having five terms rather than three, which made additional rules necessary in order to achieve a smoother response behaviour.
Rules are of the form:
IF **Current sleep cycle** IS *Awake* AND **Time available to sleep** IS *Little* AND **Quality of sleep** IS *Normal* → **Volume of alarm** IS *Low* AND **Coffee** IS *Strong*,
with the reasoning behind this rule being that because of the current sleep cycle being awake, the volume of alarm can be low; as the person hasn't slept a lot and the sleep was only of normal quality, coffee should be strong to make the person feel more awake.
Some more rules are the following:

1. IF **Current sleep cycle** IS *Fast Asleep* AND **Time available to sleep** IS *A Lot* AND **Quality of sleep** IS *Good* → **Volume of alarm** IS *High* AND **Coffee** IS *Regular*
2. IF **Last meal or drink** IS *Some Time Ago* AND **Slept day before** IS *Little* AND **Activity during day** IS *A Lot* → **Easiness of falling asleep** IS *Easy*

The following guidelines have been used for the development of the rules: 1. When the user is fast asleep, most often

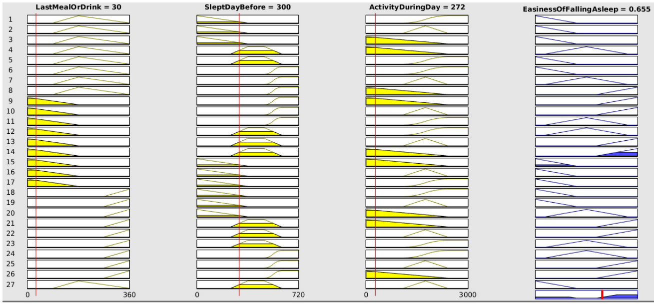

Figure 2: Rules triggered for subsystem 1

a high volume of alarm is needed to wake him up. 2. When the user has slept little the day before, he usually falls asleep quite easily.

Composition & defuzzification

We selected the max-min metric for composition and the center-of-gravity method for defuzzification, as these produced the most accurate results. The resulting surfaces can be found in the appendix.

4 Results & Analysis

Example simulation

As sleeping patterns are as different as night and day, we decided to run three example simulations: user 1 is the typical student, user 2 is a business person of the ”work hard, play hard” mindset, and user 3 is a sedate commuter. A sample image of how the triggered rules produce the output can be seen in figure 2.

We will elaborate on the scenario of user 2 as an example of the results:

- **Last meal**: 15 minutes - a late snack before going to sleep.
- **Slept day before**: 4 hours - Thursday was Ladies' Night.
- **Activity during day**: 3,000 calories - a self-conscious, guilt-ridden hour at the gym.
- **Commute time**: 20 minutes - a convenient distance to work.
- **Time to sleep**: 300 minutes - the theoretical maximum of sleeping time, as the user went to bed at 2 am and needs to rise at 7 am.
- **Current sleep cycle**: 0.9 - the user is still in the deep sleep phase, due to exhaustion and lack of sleep.
- **Quality of sleep**: 0.4 - the user is a tight sleeper, but his lifestyle takes its toll.

User	Last meal	Slept day before	Activity	Ease of sleep
1	60	360	2400	0.50
2	15	240	3000	0.17
3	120	540	1500	0.48

Table 1: Simulation outputs for subsystem 1

User	Commute time	Ease of sleep	Time to sleep	Sleep duration	Actual time
1	60	0.5	480	0.848	6.78
2	20	0.17	300	0.867	4.34
3	90	0.48	600	0.82	8.23

Table 2: Simulation outputs for subsystem 2

User	Sleep cycle	Time to sleep	Quality	Volume	Coffee
1	0.8	480	0.6	78.6	1.99
2	0.9	300	0.4	83	2.35
3	0.6	600	0.9	50	1.03

Table 3: Simulation outputs for subsystem 3

The results indicate the following for the respective users, with an emphasis on user 2:

- User 1 has a wake-up time of about 7.30 am for a bed time of 1 am, with 30 min to get ready, a commute of 60 min, and an appointment at 9 am; volume is medium to high; and coffee is strong.
- User 2 wakes up at around 6.15 am, has 25 mins to get ready, and then commutes 20min. Subsystem 1 produces an **easiness of falling asleep** of **0.166** (the lower, the easier). This intuitively makes sense, as the lack of sleep and the amount of exercise would make the user fall asleep almost instantaneously once he makes it to bed.
  Subsystem 2 produces a **sleep duration** modifier of **0.867**, i.e. the actual sleeping time is 87% of the theoretical maximum sleeping time. In this case, the user will get 4 hrs 20 min of sleep, leaving him with a reasonable time-span of 20 min to get ready before his 20 min morning commute.
  Subsystem 3 finally results in an output **alarm volume** of **83** decibels, and a **coffee strength** of **2.34** spoons of coffee. These outputs intuitively make sense given the user's deep sleep phase.
- User 3 wakes up around 6.58am with a medium volume and receives a weak coffee. Hegets ready in 30 mins roughly, then has a long commute of 90 min for a 9 am start.

Evaluation

Even though sleep is an area that is still widely undiscovered and lacking scientific rigour, our system achieves reasonable results for a variety of common use cases that leave the user not sleep deprived, but energized and facilitate a good start in the day.
In the following, we will comment on some of the design choices we made: We frame commute time as a fuzzy input to have another obvious factor that clearly influences the sleeping time. Commute time inherently, though, is a crisp value and could have just as easily been substracted from the sleeping time during post-processing. This would have robbed us of a sensible input, which is why we decided to use commute time as a fuzzy input nevertheless.

Another controversy dealt with arguably the most relevant aspect of the system, i.e. how it should determine when to wake the user. Our first intuition was to use "time of alarm" as output. Time of alarm, though, is meaningless without knowing when the user went to bed. This led us to assuming "time available to sleep" as output. This again lacks robustness without knowing if the time available to sleep is significant in relation to the time of going to bed and the moment of the first meeting. This finally led us to adopt our current approach, which is to accept the time available to sleep (computed by counting the time between going to bed and the first meeting) and manipulate it using a sleep duration modifier to produce the actual sleeping time.
In total, we are content with our system, especially as it is the first one that consists not of one but three fuzzy logic-based systems that collaborate productively and achieve a versatile output.

5 Conclusions

Sleep, due to its lack of hard scientific knowledge and inherent vagueness, is predestined as a use case for fuzzy knowledge. Our system achieves robust results, while being able to adapt to a wide range of sleeping patterns, which a crisp system wouldn't be able to do.

6 Outlook

We have discussed several more input and output parameters, which have been observed to influence sleep, but which we decided not to use for the sake of simplicity. Some of the input parameters are the following: Room temperature, sunrise time, amount of REM sleep, brightness, noise, particles in the air, air humidity, sleep quality in previous nights, medication, health. Some of these could be incorporated in additional subsystems to make the system more versatile.
In order to ensure a more pleasant wake-up, other environmental aspects, which influence waking up, can be incorporated: A light can be added to the wake-up system to simulate a natural sunrise. Ambient or natural sounds can be used. The wake-up system can communicate with a smart thermostat to start increasing the room temperature about an hour before waking up. The coffee maker can be placed in the room and can be set fifteen minutes early to wake the user with the smell of freshly brewed coffee.

7 References

References

Ahmad, K. 2014-2015. Slides. *Fuzzy logic lecture*.

Ferdman, R. A. 2014. Where the world's biggest coffee drinkers live. *Quartz*.

Gary H. Kamimori, Dagny Johnson, D. T. G. B. 2005. Multiple caffeine doses maintain vigilance during early morning operations. *Aviation, Space, and Environmental Medicine* 76:1046–1050.

Hans-Peter Landolt, Esther Werth, A. A. B. D.-J. D. 1995. Caffeine intake (200 mg) in the morning affects human sleep and eeg power spectra at night. *Brain Research* 675:67–74.

Live Science, Coffee 4 Dummies, C. R. 2014. Coffee drinking statistics. *Live Science*.

Pilcher, J. J., and Huffcutt, A. J. 1996. Effects of sleep deprivation on performance: a meta-analysis. *Sleep: Journal of Sleep Research & Sleep Medicine*.

Reyern, L. A., and Horne, J. A. 2000. Early morning driver sleepiness: Effectiveness of 200 mg caffeine. *Psychophysiology* 37:251–256.

8 Appendix

A Membership functions

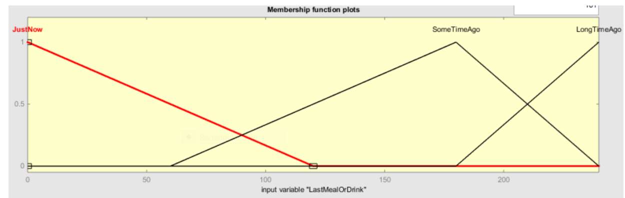

Figure 3: Subsystem 1, input 1: Last meal or drink

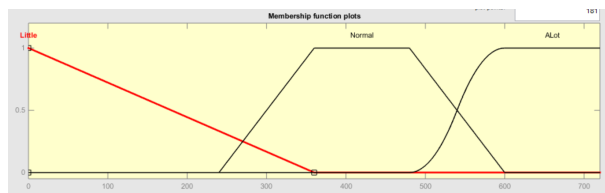

Figure 4: Subsystem 1, input 2: Slept day before

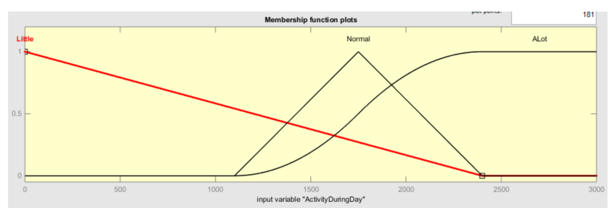

Figure 5: Subsystem 1, input 3: Activity during day

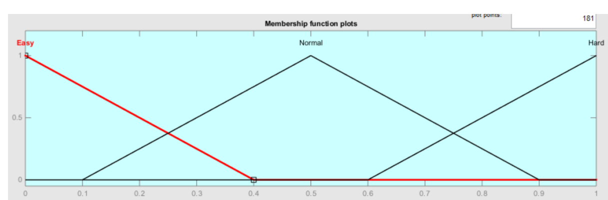

Figure 6: Subsystem 1, output 1: Easiness of falling asleep

B Surfaces

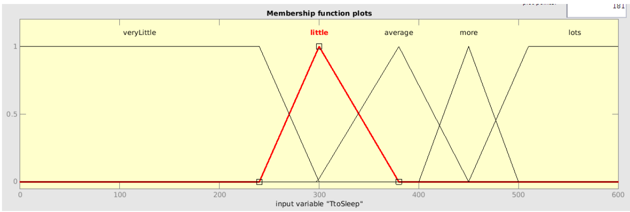

Figure 7: Subsystem 2, input 1: Time available to sleep

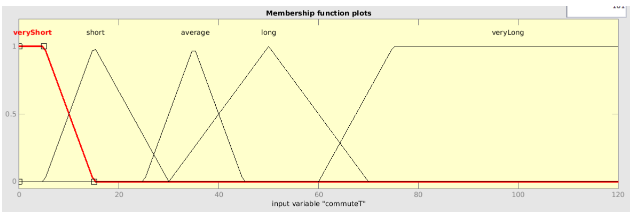

Figure 8: Subsystem 2, input 2: Commuting time

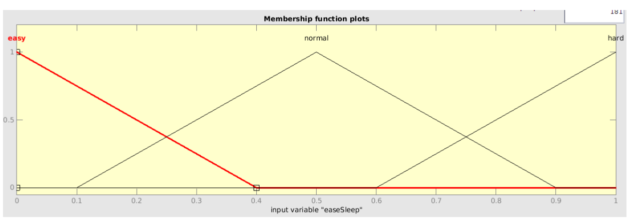

Figure 9: Subsystem 2, input 3: Easiness of falling asleep

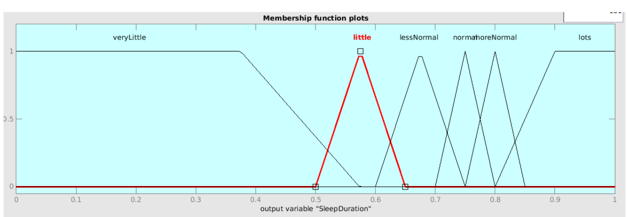

Figure 10: Subsystem 2, output 1: Sleep duration modifier

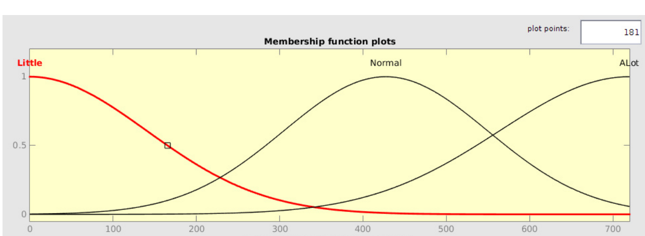

Figure 11: Subsystem 3, input 1: Time available to sleep

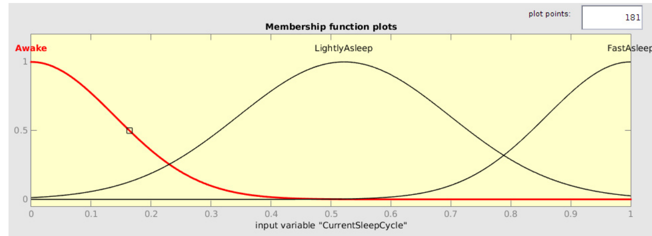

Figure 12: Subsystem 3, input 2: Current sleep cycle

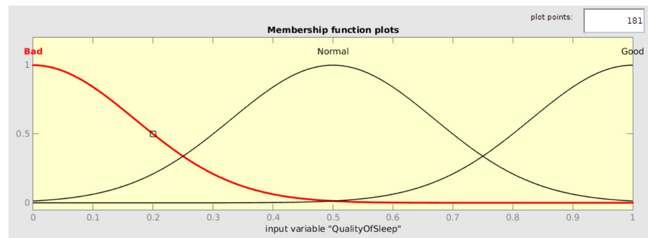

Figure 13: Subsystem 3, input 3: Quality of sleep

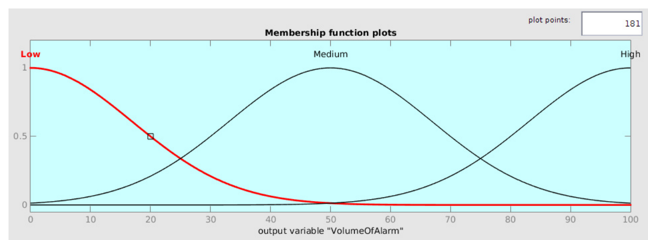

Figure 14: Subsystem 3, output 1: Volume of alarm

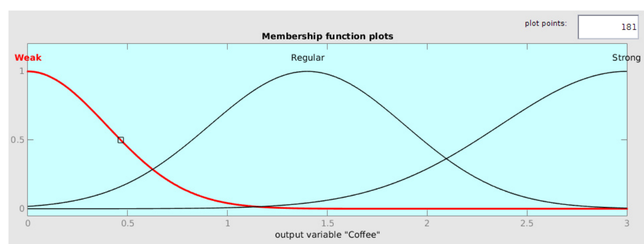

Figure 15: Subsystem 3, output 2: Coffee membership function

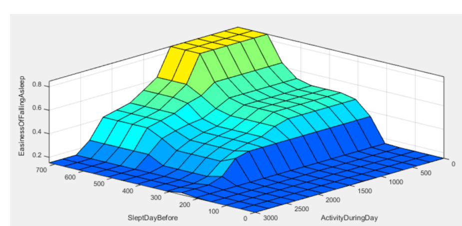

Figure 16: Subsystem 1: Activity during day, slept day before, easiness of falling asleep

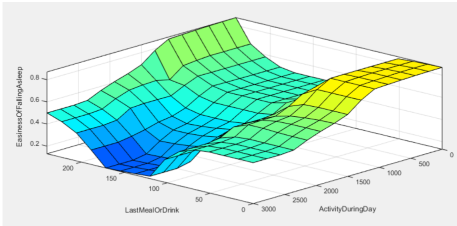

Figure 17: Subsystem 1: Last meal or drink, activity during day, easiness of falling asleep

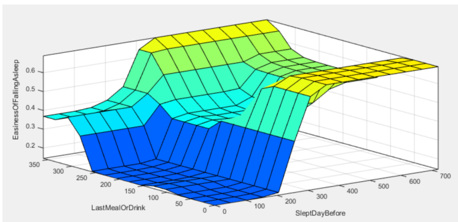

Figure 18: Subsystem 1: Last meal or drink, slept day before, easiness of falling asleep

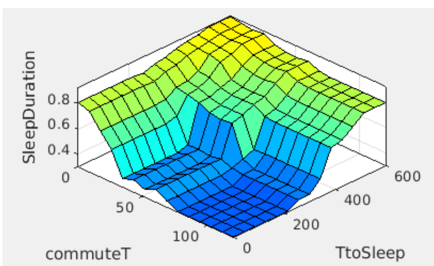

Figure 19: Subsystem 2: Commute time, time to sleep

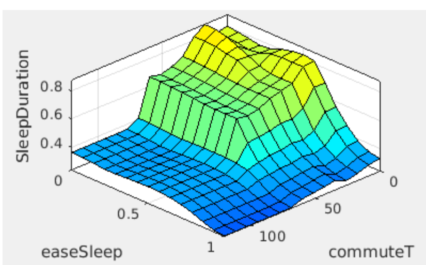

Figure 20: Subsystem 2: Ease of sleep, commute time

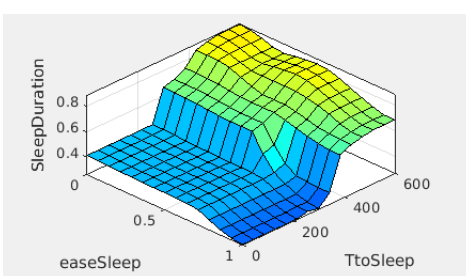

Figure 21: Subsystem 2: Ease of sleep, time to sleep

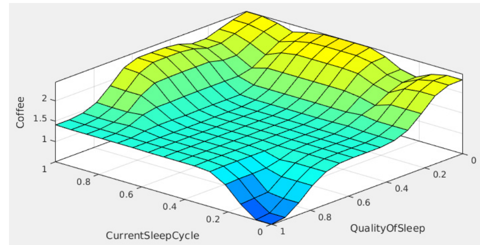

Figure 22: Subsystem 3: Current sleep cycle, quality of sleep, coffee

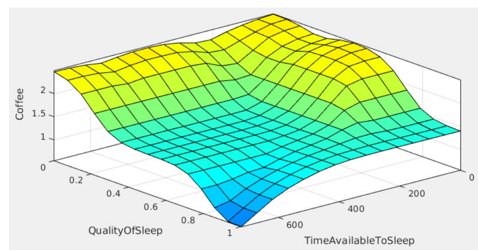

Figure 23: Subsystem 3: Time available to sleep, quality of sleep, coffee

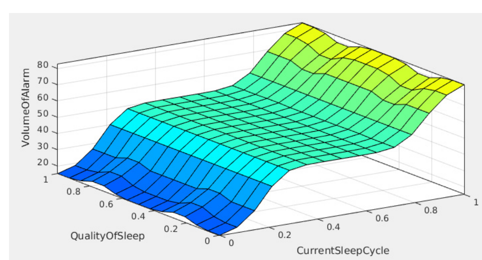

Figure 24: Subsystem 3: Current sleep cycle, quality of sleep, volume of alarm