An Artificial Intelligent Approach Using Fuzzy Logic for Sleep Quality Measurement

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ABSTRACT

Sleep is a mysterious shift in consciousness that bodies require every day. It is distinguished from wakefulness by a decreased ability to react to stimuli, but is more easily reversed than the state of hibernation. Sleep is vital for one's health and well-being. Lacking of quality sleep decreases one's functionality for the day and is detrimental to health in long term. Over the past 2 decades, actigraphy has emerged as one of the most popular methodologies to study and assess sleep–wake patterns. A lot of commercial devices have been manufactured based on this approach. However, these commercial devices do not really quantify and display the exact level of sleep quality. The same disadvantage happens for subjective assessment. This paper proposes a method using Fuzzy Logic (FL) which able to quantify the sleep quality. The FL system was developed through few vital steps: (i) Identifying the significant variables which affect the sleep quality, (ii) Determining the fuzzy set for each variable, (iii) Constructing the fuzzy rules through studying the relationship between each variable, (iv) Developing the inference system using Mamdani style. Four individuals were invited for carrying the experiments, developed FL system was used to measure their sleep quality and they were required to complete the sleep quality subjective

ISSN 1823- 5514, eISSN 2550-164X
Received for review: 2017-02-12
Accepted for publication: 2017-05-12
Published: 2017-09-15

assessments. Eventually, the results of using proposed method were compared to subjective assessment results for validation purpose.

Keywords: *Sleep, Artificial intelligences, Fuzzy Logic, Actigraphy, Sleep Quality*

Introduction

Sleep is a vital and essential routine for all living organisms, especially human body to recover from both physical and psychological fatigue that are suffered throughout the day [1]. Almost one third of human lives are spent in sleep, which serves to restore energy in order to maintain body functions [2]. Substantial studies and evidences reveal that sleep quality is contributing to one's cognitive abilities and emotional state. According to Kretzmann et al. [3], sleep benefits proper cognitive functioning, whereas sleep loss or sleep disturbance has opposing effects, resulting in cognitive deficits. In layman terms, bad sleep quality which is associated with sleep deprivation leads to excessive sleepiness, yawning, and irritability. It may also affect one's balancing, coordination, and decision-making abilities to the serious extent [3,4]. Disturbed nocturnal sleep is also related to various adverse health problems, increasing the risk of cardiovascular disease and death [2]. In short, poor sleep quality is dangerous to one's mental and physical health that can dramatically lower the quality of life.

The wide-ranging impacts of sleep problems emphasized the importance of their identification and treatment [5]. With human development and advances in science and technology, various methods in measuring sleep quality had been initiated, inclusive of both objective and subjective assessments.

According to National Institutes of Health, US Department of Health and Human Service [6], most healthy adults need between 7 to 9 hours of sleep per night to function at their best. In other words, a good sleep quality for adult requires at least 7 hours.

For normal adults, usually there are four to five sleep cycles per night, each cycle includes of rapid eye movement (REM) stage and non rapid eye movement (NREM) stage. The whole period normally proceed in the order starting from N1, N2, N3, and N4.

- N1, (NREM1) is a stage of sleep that usually occurs between sleep and wakefulness. N1 is usually known as the light sleep stage.
- N2, (NREM2) is a stage where sleepers become gradually harder to awaken. During this stage, sleeper's conscious awareness of external environment disappears.

- N3, (NREM3) is usually known as the deep sleep or slow-wave sleep. During this stage, sleepers are less responsive to the environment. Slow wave sleep is thought to be the most restful form of sleep.
- N4, REM is a stage of sleep of wakefulness and drowsiness. During this stage, most muscle is paralyzed and heart rate, breathing and body temperature become unregulated. Sleepers can experience vivid dream in this stage.

Each stage of sleep in the sleep cycle offers benefits to the sleeper. However, N3 and REM sleep stage are particularly important. A normal adult spends approximately 50% of total sleep time in N2 stage and 50% in the remaining stages [6].

Actigraphy and Fuzzy Logic

Over the past 2 decades, actigraphy has emerged as one of the most popular objective assessments to study and assess sleep–wake patterns in infants, children, and adults [7,8]. It is a non-invasive objective method to record motor activity and sleep parameters by the means of an electronic device worn on the body. The main motor activity parameter that is assessed by actigraphy is the “activity mean” [9]. Madsen et al. [10] reported that the increased popularity of actigraphy is mainly due to its non-invasive methodology, low cost, and simultaneous ability to objectively measure sleep and circadian rhythms. Actigraphy has been shown to have high correlation with polysomnography (PSG) which is the gold standard in sleep assessment [9].

Generally, the principle of actigraphy is based on a small wrist-watch like device that monitors movements for extended periods of time. It is attached to the adult’s wrist or infant’s ankle during the recording period. The devices will then records movement for extended period of time with minimal disruption of ongoing sleep in the subject’s natural environment [8]. The raw activity scores (e.g., in 1-min epochs) are then translated to sleep-wake scores based on computerized scoring algorithms [11]. There are different commercial devices in the market nowadays with their own measurement characteristics. For instance, Fitbit, WakeMate and Up (Jawbone) are the most popular and recent one. Although the existing actigraphy devices are able to indicate the total sleep time, awake time, and restless time, to the authors’ best knowledge, standard equations to quantify the sleep quality, however, is not yet reported or available in the literature. Therefore, in current research, three parameters will be taken into consideration for measuring the sleep quality using Fuzzy Logic approach.

The three parameters are total sleep time, deep sleep time, and sleep efficiency.

Fuzzy logic has been introduced by Zadeh [12] and it has been tremendously ventured into many fields since then. The fuzzy logic uses human reasoning concept in correlating some input-output relationship phenomena and its deliver the conclusion collectively according to the desire framework. In early stage, this technique has been introduced as an alternative to an analytical model correlation especially for a complex system modelling. Fuzzy logic is also useful when there is no analytical model available to correlate the input-output relationship. Such technique is represented by a linguistic rule set: IF (premise) THEN (conclusion), which the linguistic represent, the relationship of input and output of certain phenomena of the system. Many literatures reported that fuzzy logic gives an outstanding performance in artificial intelligent applications especially toward decision making [13], system prediction [14], system classification [15] and many more. For instance, fuzzy logic has showed advantages in the prediction of event causes by human factor [15].

Methodology

The flow chart of this research is shown in Figure 1. Referring to previous researches [1-11]. There are many variables affect the sleep quality such as deep sleep time, ambient temperature, heart beat and etc. In this research, only three significant variables are identified and the data of these three variables can be collected easily through current commercial products such as Fitbit, Miband and etc. Four different individuals were invited for carrying the experiments including of collecting the data. Each individual was required to wear Miband and Fitbit on the same arm along their respective sleeping period to record the required inputs. Subsequently, they were required to answer a set of questionnaire questions on the following day, which served the purpose of self-rating on their sleep quality. Three variable inputs were collected (Total Sleep Time, Total Deep Sleep Time and Sleep Efficiency) using Miband and Fitbit to measure the sleep quality using Fuzzy Logic. Results from the questionnaire were used for validation purpose.

As shown in Figure 2, the Mi Band interface displays three major sleep activities during the sleep time which are Light Sleep stage, Deep Sleep stage and Awake stage. The Light Sleep Stage is representing the N1 and N2 stages, while Deep Sleep stage representing the N3 and REM stages. The Awake Stage is representing the non-indicative sleep behavior movement. The two prominent variable inputs that were collected through this sleep activity graph were Total Sleep Time and Total Deep Sleep Time.

In addition to Miband, Fitbit was able to record the total awake/restless time and this parameter was used to calculate the Sleep Efficiency over the night. The interface of Fitbit is shown in Figure 3.

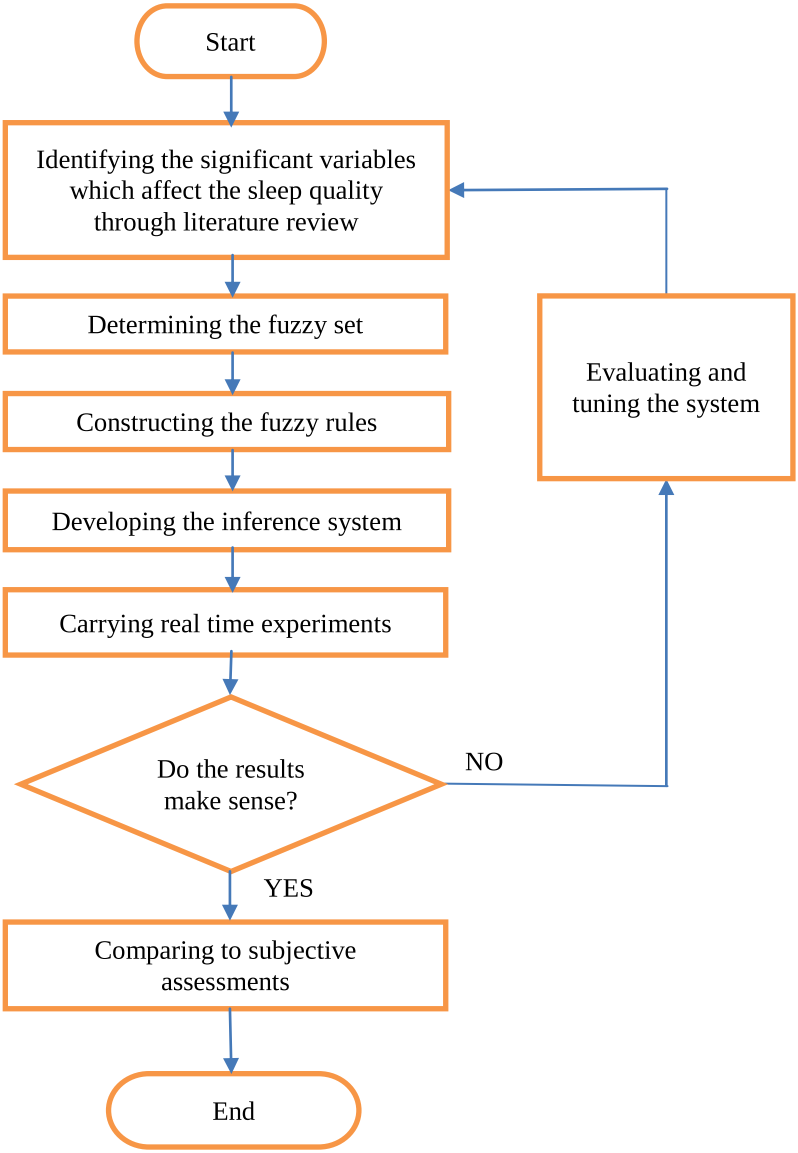

Figure 1. Flow Chart.

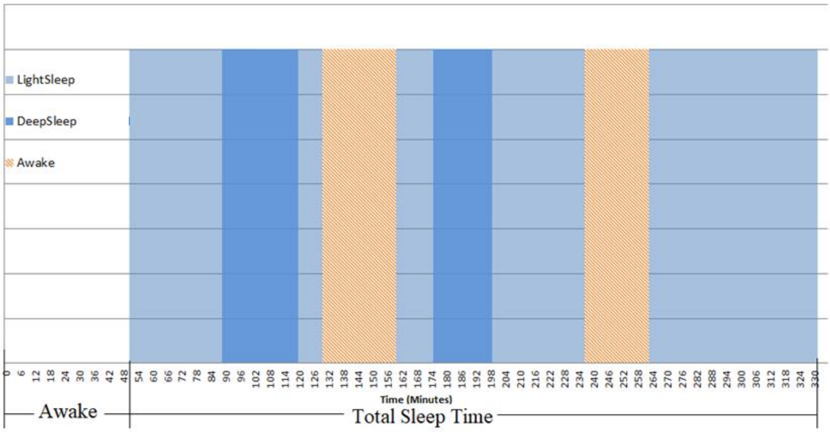

Figure 2. Sleep Activities Graph.

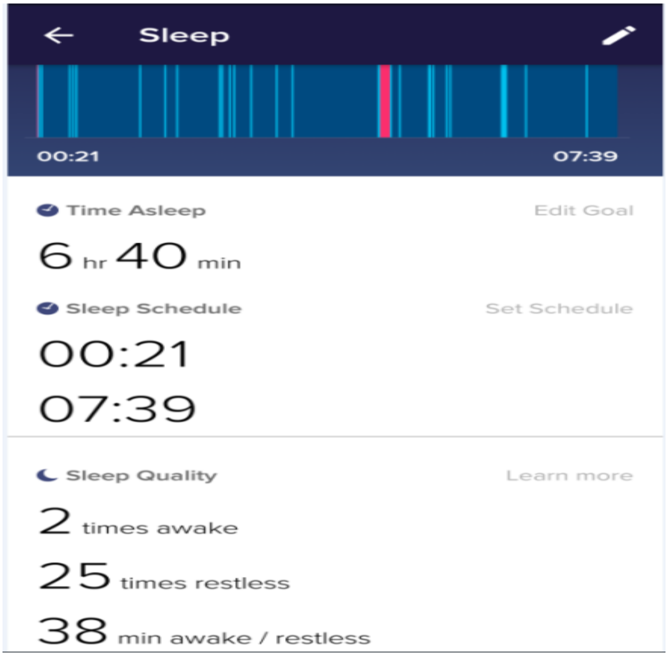

Figure 3. Fitbit Interface.

In the calculation of sleep quality, the first variable input was Total Deep Sleep Time. The fuzzy sets for this input were Short, Medium, and Long (Figure 4) and it was calculated using Equation 1. The second variable input was Total Sleep Time. The fuzzy sets for second inputs were Short, Medium, and Long (Figure 5). Similarly, the fuzzy sets for last inputs (Sleep Efficiency) were High, Medium, and Low, as shown in Figure 6. All the input functions were normalized to [0-1].

$$Total\ Deep\ Sleep\ Time\ (\%) = \frac{Total\ deep\ sleep\ time}{Total\ sleep\ time} \times 100\% \qquad (1)$$

For all fuzzy sets of three input variables, the fuzzy rule base was comprised of 27 rules. The fuzzy interference would convert all input sets to an output, after input fuzzification. The desired fuzzy output would be the Sleep Quality. In this study, the fuzzy sets for the output variable (Sleep Quality) were ranged from L1 to L9, in which L9 was the best while L1 was the poorest as shown in Figure 7.

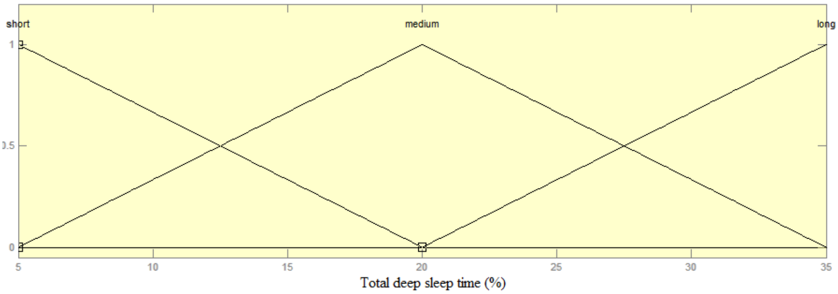

Figure 4. Membership Function Plot of The Input Variable 'Total Deep Sleep Time'.

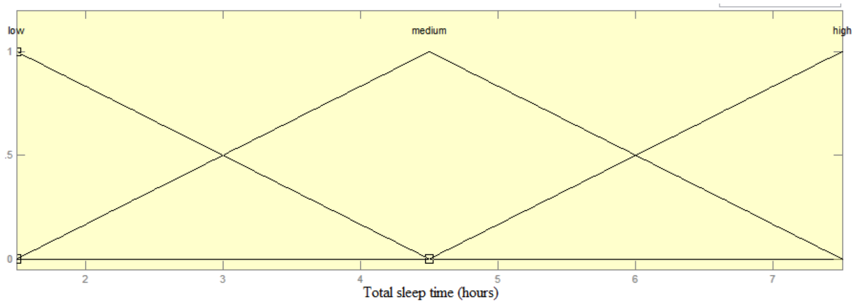

Figure 5. Membership Function Plot of The Input Variable 'Total Sleep Time'.

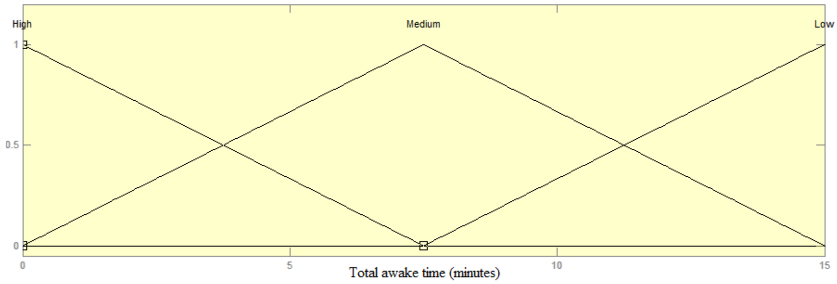

Figure 6. Membership Function Plot of The Input Variable 'Sleep Efficiency'.

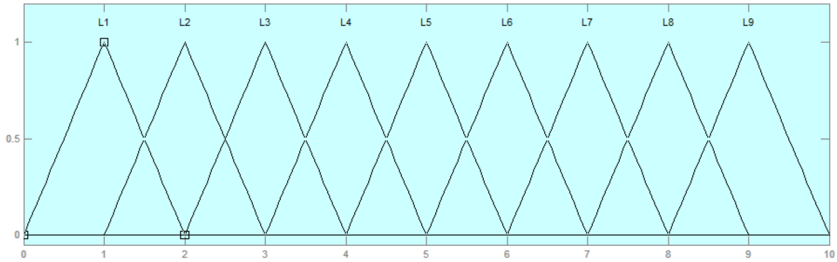

Figure 7. Membership Function Plot of The Output Variable 'Sleep Quality'.

Table 1 shows the 27 fuzzy rules set in this study for measuring the sleep quality. Also, Figure 8 presents the surface responses of the fuzzy rules which were obtained using the MATLAB toolbox (FIS).

Table 1. The Fuzzy Rule Base.

Rule No.	IF	AND	AND	THEN
1	Deep Sleep Time and REM Time is Long	Total Sleep Time is Long	Sleep Efficiency is High	Sleep Quality is L9
2	Deep Sleep Time and REM Time is Long	Total Sleep Time is Long	Sleep Efficiency is Medium	Sleep Quality is L8
3	Deep Sleep Time and REM Time is Long	Total Sleep Time is Long	Sleep Efficiency is Low	Sleep Quality is L7
4	Deep Sleep Time	Total Sleep	Sleep	Sleep Quality

	and REM Time is Long	Time is Medium	Efficiency is High	is L7
5	Deep Sleep Time and REM Time is Long	Total Sleep Time is Medium	Sleep Efficiency is Medium	Sleep Quality is L6
6	Deep Sleep Time and REM Time is Long	Total Sleep Time is Medium	Sleep Efficiency is Low	Sleep Quality is L5
7	Deep Sleep Time and REM Time is Long	Total Sleep Time is Short	Sleep Efficiency is High	Sleep Quality is L5
8	Deep Sleep Time and REM Time is Long	Total Sleep Time is Short	Sleep Efficiency is Medium	Sleep Quality is L4
9	Deep Sleep Time and REM Time is Long	Total Sleep Time is Short	Sleep Efficiency is Low	Sleep Quality is L3
10	Deep Sleep Time and REM Time is Medium	Total Sleep Time is Long	Sleep Efficiency is High	Sleep Quality is L8
11	Deep Sleep Time and REM Time is Medium	Total Sleep Time is Long	Sleep Efficiency is Medium	Sleep Quality is L7
12	Deep Sleep Time and REM Time is Medium	Total Sleep Time is Long	Sleep Efficiency is Low	Sleep Quality is L6
13	Deep Sleep Time and REM Time is Medium	Total Sleep Time is Medium	Sleep Efficiency is High	Sleep Quality is L6
14	Deep Sleep Time and REM Time is Medium	Total Sleep Time is Medium	Sleep Efficiency is Medium	Sleep Quality is L5
15	Deep Sleep Time and REM Time is Medium	Total Sleep Time is Medium	Sleep Efficiency is Low	Sleep Quality is L4
16	Deep Sleep Time and REM Time is Medium	Total Sleep Time is Short	Sleep Efficiency is High	Sleep Quality is L4
17	Deep Sleep Time and REM Time is Medium	Total Sleep Time is Short	Sleep Efficiency is Medium	Sleep Quality is L3
18	Deep Sleep Time and REM Time is Medium	Total Sleep Time is Short	Sleep Efficiency is Low	Sleep Quality is L2
19	Deep Sleep Time and REM Time is Short	Total Sleep Time is Long	Sleep Efficiency is High	Sleep Quality is L7
20	Deep Sleep Time and REM Time is Short	Total Sleep Time is Long	Sleep Efficiency is Medium	Sleep Quality is L6

21	Deep Sleep Time and REM Time is Short	Total Sleep Time is Long	Sleep Efficiency is Low	Sleep Quality is L5
22	Deep Sleep Time and REM Time is Short	Total Sleep Time is Medium	Sleep Efficiency is High	Sleep Quality is L5
23	Deep Sleep Time and REM Time is Short	Total Sleep Time is Medium	Sleep Efficiency is Medium	Sleep Quality is L4
24	Deep Sleep Time and REM Time is Short	Total Sleep Time is Medium	Sleep Efficiency is Low	Sleep Quality is L3
25	Deep Sleep Time and REM Time is Short	Total Sleep Time is Short	Sleep Efficiency is High	Sleep Quality is L3
26	Deep Sleep Time and REM Time is Short	Total Sleep Time is Short	Sleep Efficiency is Medium	Sleep Quality is L2
27	Deep Sleep Time and REM Time is Short	Total Sleep Time is Short	Sleep Efficiency is Low	Sleep Quality is L1

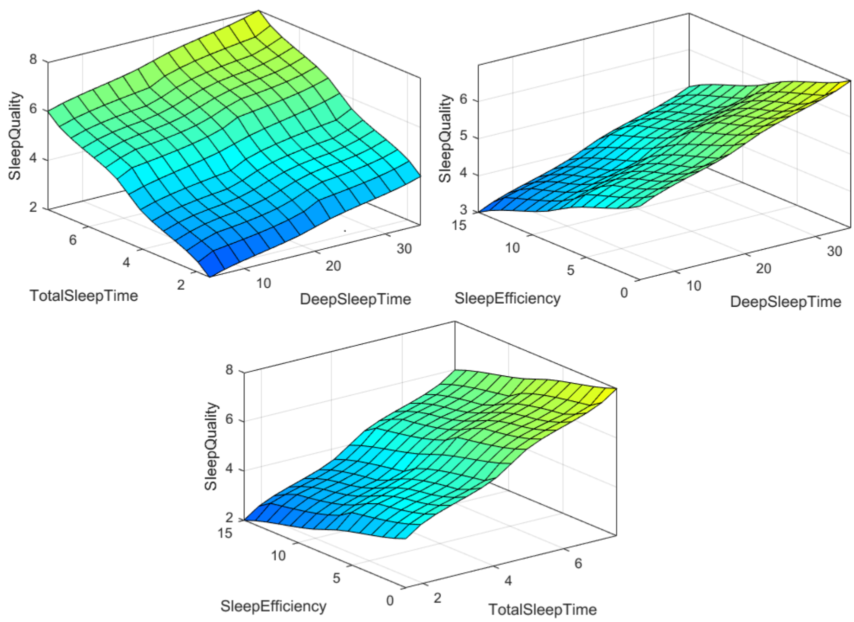

Figure 8. Surface Response of the Fuzzy Rules.

On the other hand, even though questionnaire was considered as a subjective assessment but it had been extensively employed by other researchers in measuring sleep quality as well. Among them, questionnaire set by Huffington [17], and Pittsburgh Sleep Quality Index (PSQI) questionnaire [18] were the famous one. In this research, questionnaire result was used as supplementary information in validating the results generated by Fuzzy Logic in predicting the sleep quality. A total of 6 questions which were related to the variable inputs were designed to manually estimate the sleep quality based on the sample's self-evaluation. Minimum score for each question was zero and maximum score was three. The total score for the questionnaire was 18 and it was normalized to the rating from one to nine, with one indicated the poorest sleep quality.

Below are the questions which being asked in the questionnaire:

1) How long does it take you to fall asleep?

0 – 15 mins	3
15 – 30 mins	2
30 – 60 mins	1
> 60 mins	0

2) How would you rate your sleeping quality?

Very Good	3
Good	2
Poor	1
Very Poor	0

3) How many hours did you sleep?

> 6 hours	3
Around 5 – 6 hours	2
Around 4 – 5 hours	1
< 4 hours	0

4) Do you feel energetic in the morning?

Strongly Agree	3
Agree	2
Disagree	1
Strongly Disagree	0

5) How many times did you awake from you sleep during the night?

None	3
1	2
2	1
> 2	0

6) How would you rate your mood after your sleep?

Very Good	3
Good	2
Bad	1
Very Bad	0

Results and Discussions

At this moment, there are very limited researches which are using artificial intelligence approach for measuring sleep quality especially using Fuzzy Logic. This research can be considered as a pioneer research in this area. Three fuzzy inputs were identified as significant inputs. Undeniable, there are many variables or parameters can be used for measuring sleep quality. The accuracy of results can be improved if the number of variables is increased. However, throughout the studies, the number of questions in questionnaire for measuring someone sleep quality is very scarce. Hence, the distribution of the marks is very scattering. It will make the validation process become very difficult if the number of inputs is increased. Thus, as a preliminary research, three significant inputs is sufficient. Besides, each input consists of three fuzzy sets and there are total 27 fuzzy rules for this measuring system.

Fuzzy sets can have a variety of shapes. However, a triangle or a trapezoid can often provide an adequate representation of the expert knowledge, and at the same time significantly simplifies the processing of computation. This has been proven in a lot of researches which using Fuzzy Expert System [13-15]. Conventionally, there are two common fuzzy inference techniques which are Mamdani style and Sugeno style inference. As compared to Sugeno style, Mamdani style fuzzy inference entails a substantial computational burden. However, author found that Mamdani style is widely accepted for capturing expert knowledge. It allows the user to describe the expertise in more intuitive, more human like manner. This research was using the Mamdani style as the fuzzy inference for the system as shown in Figure 9.

Basically, the Mamdani style fuzzy inference process is performed in four steps: fuzzification of the input variables, rule evaluation, aggregation of the rule outputs and finally defuzzification. The first step was to take the crisp inputs (Deep Sleep Time, Total Sleep Time, and Sleep Efficiency) and determined the degree to which these inputs belonged to each of the appropriate fuzzy sets. The second step was to take the fuzzified inputs and applied them to the antecedents of the fuzzy rules. Aggregation is the process of unification of the outputs of all rules. In other words, the membership function of all rule consequent previously clipped or scaled and combine them into a single fuzzy set. The last step was the defuzzification process. In this research, the defuzzification method was centroid technique.

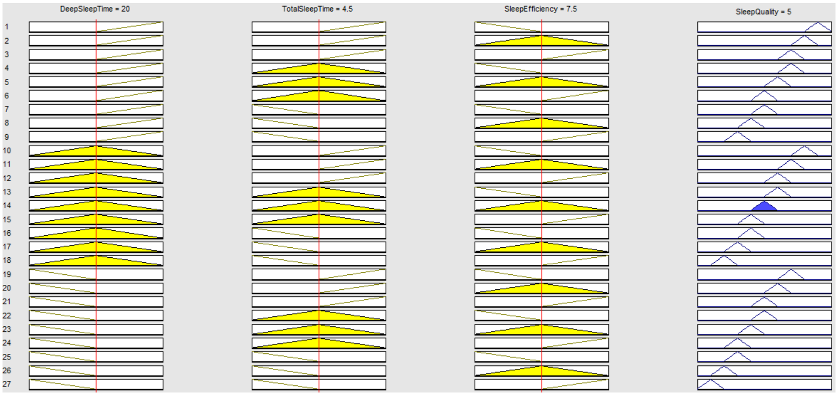

Figure 9. Fuzzy Inference Using Mamdani Style Inference.

Table 2 shows the comparison between subjective assessment (questionnaire) and proposed method in predicting the sleep quality.

Four individuals were invited for carrying the experiments. The age range was from 25 to 30. The gender for individual A and B is Male, while individual C and D are Female. Before carrying these experiments, they were confirmed in healthy condition.

For the individual A and D, no significant difference was observed between subjective assessment and proposed method. For individual B, the difference was slightly higher as compared to first and last individual. This might be due to the nature of question 6 which was rather subjective which was related to the individual’s mood. For individual C, the difference between subjective assessment and proposed method in day 1 was extremely high which is above 1. This might be due to other uncertainties which affected the individual’s sleep quality which couldn’t be reflected through proposed Fuzzy Logic approach such as sleeping environment, mentally disorder, and etc.

However, from the overall results, it shows that the average of differences is 0.45. In other words, the results from subjective assessment were very consistent to the proposed method. For subjective assessment, it classified sleep quality into different levels while the proposed method was able to quantify the sleep quality. In order to improve the accuracy of proposed method, more variables can be taken into consideration such as sleeping environment, ambient temperature, and etc. For validation purpose, more questions can also be included into the questionnaire in order to balance out the extreme subjective questions.

Table 2. Comparison between Subjective Assessment and Fuzzy Logic.

Individual	Day	Rating		
		Questionnaire	Fuzzy Logic	Difference |(Questionnaire Rating - Fuzzy Logic Rating)|
A	Day 1	6	5.85	0.15
	Day 2	5	5.08	0.08
	Day 3	6	5.9	0.1
B	Day 1	7	7.78	0.78
	Day 2	7	7.77	0.77
	Day 3	6	6.62	0.62
C	Day 1	5	6.38	1.38
	Day 2	6	6.53	0.53
	Day 3	5	5.36	0.36
D	Day 1	6	5.85	0.15
	Day 2	8	7.7	0.3
	Day 3	6	5.8	0.2
Average				0.45

Conclusion

All the time, the only way to measure sleep quality is by using subjective assessments. However, from subjective assessments, one cannot figure out the main factors which are truly affecting the resulting sleep quality. In this research, a few variables had been integrated into the proposed method in measuring one's sleep quality such as Total Sleep Time, Deep Sleep Time and Sleep Efficiency. The results were promising and very similar to subjective assessment (average difference < 0.5) but the accuracy still can be improved if more factors can be taken into consideration.

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