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An Expert System for Diagnosis of Sleep Disorder Using Fuzzy Rule-Based Classification Systems

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An Expert System for Diagnosis of Sleep Disorder Using Fuzzy Rule-Based Classification Systems

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Abstract. Sleep disorder is an anomaly that could cause problems for someone' sleeping pattern. Nowadays, it becomes an issue since people are getting busy with their own business and have no time to visit the doctors. Therefore, this research aims to develop a system used for diagnosis of sleep disorder using Fuzzy Rule-Based Classification System (FRBCS). FRBCS is a method based on the fuzzy set concepts. It consists of two steps: (i) constructing a model/knowledge involving rulebase and database, and (ii) prediction over new data. In this case, the knowledge is obtained from experts whereas in the prediction stage, we perform fuzzification, inference, and classification. Then, a platform implementing the method is built with a combination between PHP and the R programming language using the "Shiny" package. To validate the system that has been made, some experiments have been done using data from a psychiatric hospital in West Java, Indonesia. Accuracy of the result and computation time are 84.85% and 0.0133 seconds, respectively.

1. Introduction

Sleep is human's basic need [1]. It is considered substantial because sleeping is a process when human's cellulars are generating new cells, regenerating damaged cells (i.e., natural healing mechanism), giving the organs time to rest, and also keeping body's metabolism and biochemistry process in balance [2]. Therefore, when someone does not have a good sleep, then he might has a sleep disorder. An example of this issue has been conducted by J. Kales and S. Healey in Los Angeles, and it results of the following data: 42,5% are anguishing insomnia, 11,2% are having nightmare, 7,1% are oversleep, 5,3% are delirious, and 2,5% are sleep walking [3].

Basically, sleep disorder happened in a long period could reduce cognitive capability, including less concentration, easy to forget, slow in thinking process, also could affect relationship between friends and families, change on biological sleep cycle, immune deficiencies, reduce work performance, easily offended, depression, exhaustion, and eventually could endanger self safety or any others [4]. Based on this explanation, it can be concluded that sleep disorder is a health problem that has to be solved.

In order to solve sleep disorder, mostly patients should consult in face to face with medical assistance [5]. Yet, it could inflict other problems because of time and distance. Therefore, alternative solutions should be proposed, which is by developing a consultation media that could be accessed by many people and not rely on time and distance. Expert systems are basically able to handle these issues. Moreover, the systems have been applied to many areas. For example, it

was applied in the disaster management system, namely flood control and defenses [6]. We can also find other applications of the expert systems, such as in determining defence strategy in basketball [7], for estimating intrinsic susceptibility in fishing [8], and for detecting breast cancer [9], fever disease [10], hearth disease [11], and diabetes detection [12]. Regarding with solving for sleep disorder, we can find the following research: [13, 14]. Moreover, there are some studies related to solving sleep disorder by using machine-learning approaches, such as [15, 16].

In this research, we attempt to develop an expert system that capable to provide diagnostic possibility of someone suffering sleep disorder using FRBCS. It is a part of well known methods in soft computing based on fuzzy concepts [17] to solve classification problem [18]. It is capable to classify uncertainty value into classes of groups that had been determined before. Furthermore, FRBCS can generate a model with two ways: (i) expert systems where knowledge is determined by human experts, and (ii) machine-learning approach requesting data training for generating a model. In this case, we are using FRBCS as the expert-system model.

The remainder of this paper is structured as follows. Section 2 and 3 briefly introduces to sleep disorder and fuzzy sets along with FRBCS. In Section 4, we describe how to construct a model based on FRBCS and implement the model. Section 5 presents results and discussion of some experiments. Finally, Section 6 concludes the paper.

2. Sleep Disorder

Sleep disorder happens when someone is not experiencing NREM or REM cycle normally. Sleep disorder can be interpreted as a disorder that can cause problems in someone's sleep pattern, either because of wakeful, frequent waking at night, or incapability to back to sleep after awakens [19].

There are two types of sleep disorder disease, which are organic type and non-organic type (functional). Organic sleep disorder type can be observed by changes in someone's nerve. Whilst, functional sleep disorder can be observed by someone's psychiatric and behavior. In this research, we are focusing on functional sleep disorder, which is divided into 4 types of sleep disorder: insomnia, depression, anxious, and psychotic [19]. The following is an explanation about these type of sleep disorder:

(i) Insomnia: Its common symptom is inability to sleep or unable to sleep well. Including getting up early in the morning. Basically, insomnia embraces so many this, such as hard to sleep well and even someone who awake from sleep but still have not had enough sleep can also be included as insomnia [20].

(ii) Depression: It is a bad mood which is occurring in a period of time. When someone suffering from depression, he will feel prolonged sad, desperate, doesn't have motivation to do any activity [21]. Basically, besides causing insomnia, depression also inflicts desire to sleep all the time because he want to run away from his problem. Depression is capable to cause insomnia and vice versa.

(iii) Anxious: Anxiety can be defined as an unpleasant emotional state, which is characterized by subjective feelings such as tension, anxiety, worry, and also characterized by active central nervous system [21]. Anxiety is also a bodily diseases and mental disorders, as well as highly interrelated. In psychological terms, this disorder is called Anxiety Disorders (AD). One possible cause is a chemical imbalance in the body, changes in brain structure, environmental, trauma, phobia, etc.

(iv) Psychotic: It is a mental disorder that characterized by the inability of individuals to assess the reality of the matter, so that people who have this disease have major symptoms of hallucinations, delusions and garbled speech [21].

Generally psychotic triggered by a person's inability to resolve the problem that is received by someone. How to control, treat, and respond to the problem is very different from one person to

another, so that the level of severity of psychotic suffered very diverse although equally struck by the same problem.

3. Fuzzy Sets and Fuzzy Rule-Based Classification Systems

Fuzzy set theory proposed by Zadeh in 1965, as an extension of classical set theory to model sets whose elements have degrees of membership [17]. So, instead of having two values: a member and non-member, fuzzy set allows the degree of membership set, which is defined by a value between zero and one. The value of one means that an object is a member of the set, a value of zero means that it is not a member, and the value somewhere in-between shows the value of partial membership. This membership can be defined by membership functions.

Fuzzy set theory provides tools to effectively represent the concept of linguistic variables and rules, be natural to represent the model of a human expert knowledge. A key concept is that of the linguistic variables, defined as a variable whose value is a linguistic term, each with semantics described by fuzzy sets [22]. Value refers to the label to represent linguistic knowledge means determined by the degree of membership functions. For example, a_1 = "cold" with the level of $\mu = 0.8$ means that the variable a_1 has a linguistic value represented by the label "cold", whose meaning is determined by the degree of 0.8.

In this study, we use the trapezoidal membership function that can be expressed as follow:

$$\mu_{T(a,b,c,d)(X)} = \begin{cases} 0 & x \leq a \text{ or } x > c \\ \frac{x-a}{b-a} & 0 < x \leq b \\ 1 & b < x \leq c \\ \frac{x-d}{c-d} & c < x \leq d \end{cases}$$

And for the operation T-Norm, we use the following expression:

$$\mu_{A \cap B}(X) = min(\mu_A(X), \mu_B(X)),$$

while S-Norm, the following equation is used:

$$\mu_{A \cup B}(X) = max(\mu_A(X), \mu_B(X)).$$

FRBCS is a variant of fuzzy rule-based systems, which is used for handling classification tasks. The main characteristic of classification is that the consequents are in the form of a class or category. Therefore, in this type of model we can divide the symptoms section in the form of linguistic variables, and the consequent change to become part of the class C_j of a specified class $C = C_1, \ldots, C_M$. The simplest form of fuzzy rules introduced by Chi et. al. in 1996 was built with the class at the consequent [23]:

$$\textbf{IF } X_1 \text{ is } A_1 \text{ and } \ldots \text{ and } X_n \text{ is } A_n \textbf{ THEN } Y \text{ is } C_1,$$

4. Model Construction and Software Implementation for Sleep Disorder

In this section, a model is constructed by using FRBCS as illustrated in Figure 1. It can be seen that basically the processes can be divided into two parts: model construction and prediction over new data. First, an FRBCS model, known as knowledge, contains rulebase and database. Rulebase is a set of fuzzy rules while database contains label definitions and membership functions. Then, we predict new data by considering the obtained model and processes on FRBCS.

In fact, there are two strategies to build a model, which are by learning from data and by consulting with experts. In this case, we focus on developing a model by consulting with human experts. Therefore, the following are processes to obtain a model by consulting experts:

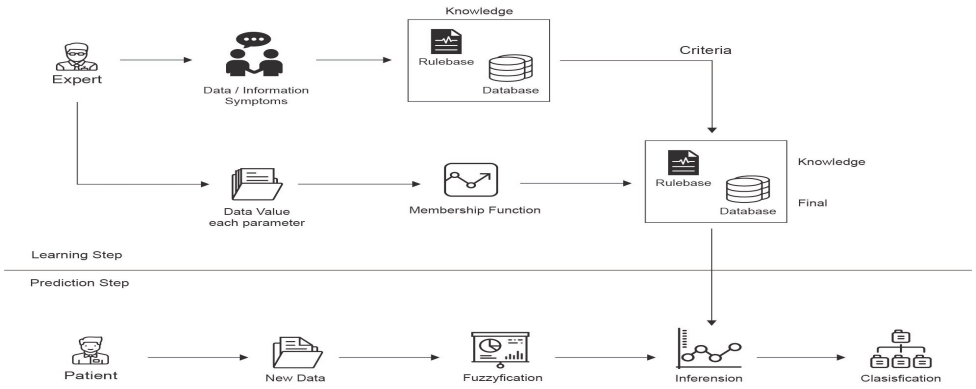

Figure 1. Model development for sleep disorder.

(i) To determine influencing symptoms: After studying literatures and consulting experts, we define 12 symptoms, as follows: physical disorder (G01), less concentration (G02), mood changing (G03), awakened frequency (G04), nightmare frequency (G05), hallucinations (G06), supposition (G07), talk chaotic (G08), diet changing (G09), moody (G10), hopeless (G11), and agitated (G12).

(ii) To determine database: In this step experts firstly need to define fuzzy labels on each symptom. In this case, we only consider two labels: "low" and "high", where the observation takes between 0 and 7 days. Therefore, we can draw the following membership functions for all symptoms:

$$\mu_{(low)}(X) = \begin{cases} 1 & x \leq 2 \\ \frac{5-x}{4} & 2 < x < 5 \\ 0 & x \geq 5 \end{cases} \qquad mu_{(high)}(X) = \begin{cases} 0 & x \leq 2 \\ \frac{x-2}{3} & 2 < x < 5 \\ 1 & x \geq 5 \end{cases}$$

(iii) To determine rulebase: A set of rules is obtained by consulting with experts. In this case, there are 392 rules collected in this step. These rules have represented four types of sleep disorders: insomnia (P01), depression (P02), anxious (P03), and psychotic (P04). For example, we have the following rules:

$R1:$ **IF** $G01$ is $high$ and $G02$ is $high$ and $G03$ is $high$ and $G04$ is $high$ **THEN** $P01$

$R2:$ **IF** $G01$ is $high$ and $G02$ is $high$ and $G03$ is low and $G04$ is low and $G09$ is low and $G10$ is $high$ and $G11$ is $high$ **THEN** $P02$

So, it can be seen that the main advantage by using FRBCS is that rules representing knowledge are in fuzzy terms so that naturally we can understand easily.

(iv) To reduce and optimize the rulebase: Since there are more than 100 fuzzy rules generated by experts, we have to reduce them by considering the following criteria: deleting redundant rules, deleting minor rules conflicted with the major ones, and choosing the simpler rules. From this step, we finally obtain 42 fuzzy rules.

So, by following four steps above, we obtain knowledge representing the FRBCS model containing rulebase and database. Then, this model will be used to predict new data.

For prediction, actually we just follow common procedures in FRBCS as explained in [18, 23, 24]. In this stage, we need to perform fuzzification, inference, and classification. In fuzzification, converting real values into fuzzy labels, and then their degrees of membership

Table 1. Results: 33 samples of patients

No	G01	G02	G03	G04	G05	G06	G07	G08	G09	G10	G11	G12	Pred	Actual
1	6	7	7	7	5	5	6	5	7	7	7	0	P01	P04
2	5	6	5	4	0	1	2	0	5	7	5	0	P02	P02
3	7	4	5	6	0	2	1	0	4	1	2	7	P03	P03
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
31	7	7	1	1	1	1	1	1	1	1	1	1	Neg	Neg
32	4	0	0	0	5	0	0	0	0	0	0	2	Neg	Neg
33	5	6	4	0	0	0	0	0	4	6	0	0	P02	P02

function is calculated. Inference refers to determine weight according to the operator T-norm and S-norm, so that we know which rules will be fired. Based on inference, then we decide which decision should be taken.

After designing the methodology for solving the problems, we implement it into system by using the "shiny" package [25] that connect two languages: PHP and R. It means we can basically access R through the web GUI as illustrated in Figure 2.

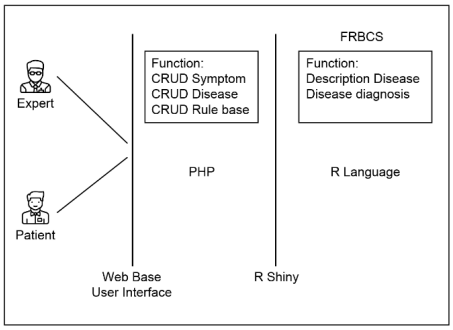

Figure 2. Architecture of the system.

5. Results and Discussion

The data used for testing are 33 samples obtained from one of the Psychiatric Hospital in West Java. The data consist of experienced symptoms that may be diagnosed as sleep disorder.

Table 1 shows some patients who have some experiences on related symptoms and their predicted and actual diagnosis. The symptoms, which are $G01$, $G02$, ..., $G012$, have values between 0 to 7 days. Diagnosis of the samples are $P01$, $P02$, $P03$, $P04$, and Neg representing insomnia, depression, anxious, psychotic, and negative for all diseases.

From these results, we obtain the accuracy of the experiments, which is 84.85% with the average of computation cost is 0.0133 seconds. In more detail, we have calculated confusion matrix on predicted and actual values. From this analysis, we obtained several measurements, as follows: $1.277e-10$ for P-value, 0.8099 for Kappa, Sensitivity of each class (i.e., 0.8333, 0.7, 1, 0.8571, and 1 for Neg, $P01$, $P02$, $P03$, and $P04$, respectively), and Specificity of each class (i.e., 1, 1, 0.9259, 0.9615, and 0.9310 for Neg, $P01$, $P02$, $P03$, and $P04$, respectively). Basically, it means that the proposed method can be used to predict sleep disorder effectively.

6. Conclusion and Future Work

The research can be summarized as follows:

(i) We have provided a model design to predict diagnosis of sleep disorder by using fuzzy rule-based classification systems.

(ii) According to the experiments, we obtained a reasonable result, with the accuracy of 84.85%. Moreover, the average of the computation time is 0.0133 seconds.

As future work, we plan to extend the diagnosis of sleep order by using Rough Set Theory [26].

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