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Fuzzy Logic System for Menstrual Cycle Interpretation Based on BBT Data

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Abstract: Basal body temperature (BBT) data have been used for so long as a simple method in estimating the day of ovulation occurred and to understand menstrual cycle that is unique for every woman. The BBT is considered to be a reliable ovulatory index, since most women will have increased temperature in the luteal phase of the cycle. However, the problems faced are the studies of validating the efficacy using BBT and lack of research. Therefore, according to these problems, a fuzzy logic system for the predictions of ovulation occurrence, follicular and luteal phase length has been constructed to interpret the BBT data effectively and this system has been implemented on Arduino Mega 2560 microcontroller for portability purpose. As a result, according to six samples of open source BBT data obtained from the Fertility Friend website, the system enables to predict the ovulation occurrence and follicular and luteal phase length with 71.43 % of accuracy.

Keywords: Fuzzy logic, menstrual cycle, basal body temperature.

1. Introduction

Basal body temperature (BBT) has been utilized since thermometers were created to detect the presence of ovulatory cycles. BBT is the lowest body temperature achieve during sleep and usually straight away taken after woke up [1]. Many practitioners have learn on the most proficient method to consolidate BBT in terms of diagnosis and evaluation in the treatment. However, the issues are the absence of research and scientific study approving the viability of using BBT for menstrual cycle.

Menstrual cycle is a series of natural processes that women body goes through. During the period cycle, the hormone levels rise and fall, depending on which stage of the menstrual cycle. These hormones can also affect mood and level of energy. Each woman's cycle has a different number of days due to the lifestyle and environment factors. Normally, the average of menstrual cycle is 28 days long which range from 21 to 35 days in adults and from 21 to 45 days in young teens [2].

This cycle consists of three phases which are follicular phase (FP), ovulation phase (OP), and luteal phase (LP). FP is where the luteinizing hormone (LH) and follicle stimulating hormone (FSH) act on ovaries to stimulate follicle growth. The follicles produce estrogen and progesterone hormone. In this phase, body temperature is at low and steady until at the end of this phase. The estrogen level will rise and reach a point that causes a rapid rise in LH that indicates the follicle is matured and it will release the egg, which is known as the OP. During this phase, the BBT measurement is low and followed by the rising peak of temperature the day after the ovulation is happen, which is known as biphasic pattern [3]. However, not every women ovulate with increasing of temperature but normally the body temperature will rise after the ovulation happen, which is called a monophasic pattern where the body temperature does not show the rise in body temperature [4]. The maximum period for ovulation phase is only in one day. LP is start when the estrogen level is drastically fall and the egg travels down the Fallopian tube and the process of fertilization or implantation may occur. Here, the temperature is high and steady. This is because progesterone level is high and affected the BBT measurement to be high [2]. However, at the end of the cycle body temperature will drop if there is no pregnancy happen. Monitoring the BBT can identify the change in temperature that occurs before and after ovulation [5].

Previous studies have demonstrated that adjustments in the body temperature reflect the hormonal changes fundamentally in progesterone and estrogen, which could affect the women's health and can make body temperature either increase or decrease. This will reflect the changes in the menstrual cycle, for example the duration of phase and the ovulation process [6]. In order to validate the efficacy of using BBT for menstrual cycle, a system should be developed to interpret the menstrual cycle based on BBT measurement. There are many types of computational intelligent that can do interpretation automatically such as Artificial Neural Networks,

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Evolutionary Computation, and Fuzzy Logic. In this research, Fuzzy Logic will be used as a method to develop the menstrual cycle interpretation system.

Fuzzy logic is a logical system, which is an extension of multivalued logic related to the concept of a linguistic variable, canonical form, fuzzy if-then rule, fuzzy quantification, the extension principle, the compositional rule of inference and interpolative reasoning, is not addressed in traditional multivalued logic systems. This is the reason why fuzzy logic has a much wider range of applications than traditional systems. In its wide sense, fuzzy logic is fuzzily synonymous with fuzzy set theory established by Prof. Zadeh in 1965 [7], which is the theory of classes with unsharp boundaries. Fuzzy logic has routinely been shown to outperform classical mathematical and statistical modeling techniques for many applications involving the modeling of real world data. For example, fuzzy logic has found wide acceptance in the field of systems control and medical field.

In the medical area, especially, in oriental medicine, most medical concepts are fuzzy. The imprecise nature of medical concepts and their relationships requires the use of fuzzy logic which can defines inexact medical entities as fuzzy sets and provides a linguistic approach with an excellent approximation to texts. It offer reasoning methods capable of drawing approximate inferences and has been used in medical area to compute and solve complex data or reasons such as medical classification diagnosis, lung cancer, medical image processing and etc. In nearly every one of these applications fuzzy logic in medical system have been shown to outperform the traditional method, yet highly advanced in digital medical reasoning and effectively be a model of a complex real world data that based on a set of historical observations on a time series, serve as the input data to the forecasting method that produces an output of the forecast or future value of the time series of interest. Therefore, in this study, the interpretation system of the BBT data will be developed by using fuzzy logic as data processing to understand the complex data in menstrual cycle towards better healthcare for women.

2. Designing Menstrual Cycle Interpretation System Based on BBT using Fuzzy Logic

The information of menstrual cycle such as day of ovulation (DO), the length of FP and LP are important in the BBT data interpretation [8,9]. Based on the previous research studies [6, 10, 11], they can be obtained using the mathematical formulae as in equation (1) to (3) and the values are summarized according to the type of menstrual cycles as shown in Table 1.

2.1 Menstrual Calculation

This section will explain on how to calculate the DO and the follicular days, FD and the luteal days, LD. The DO is taken from the middle of the last day cycle, LDC of one menstrual cycle as stated in equation (1). As in equation (2), the FD is equal to the *DO* is minus by one because the DO occurs in one day only and according to equation (3), the LD is representing by the LDC minus by the DO.

$$\mathrm{DO} = \frac{\mathrm{LDC}}{2} \tag{1}$$

$$\mathrm{FD} = \mathrm{DO} - 1 \tag{2}$$

$$\mathrm{LD} = \mathrm{LDC} - \mathrm{DO} \tag{3}$$

DO : Day of ovulation
FD : Follicular days
LD : Luteal days
LDC : Last day cycle

2.2 Menstrual Cycle Table

Table 1 shows the ranges of FD and LD and the range of DO for three types of the woman's menstrual cycle length which are short, medium and long. The range for normal length of FD is between 9 to 11 days, 12 to 15 days and 16 to 21 days for the types of a woman's menstrual cycle in short, medium and long, respectively. Besides, the range for normal length of LD is between 11 to 13 days, 14 to 16 days and 17 to 23 days for the types of a woman's menstrual cycle in short, medium and long, respectively. Therefore, below and above these ranges, the length of FD and LD can be considered as short and long, respectively. Meanwhile, the range of DO is 6 to 14 days, 11 to 18 days and 14 to 24 days for the types of a woman's menstrual cycle in short, medium and long, respectively.

Table 1 The ranges of follicular days, day of ovulation and luteal days based on the type of menstrual cycles.

Type of menstrual cycles	**Range of follicular days, FD (days)**	**Range of day of ovulation, DO (day)**	**Range of luteal days, LD (days)**
SHORT (21 - 25) days	9 - 11	6 – 14	11 - 13
MEDIUM (26 - 32) days	12 - 15	11 – 18	14 -16
LONG (33 – 45) days	16 - 21	14 – 24	17 - 23

2.3 Fuzzy Logic Development for BBT Data Interpretation

A fuzzy logic development for the BBT data interpretation includes designing block diagrams of the fuzzy logic system using a MATLAB fuzzy logic tool, determining parameter values of membership functions (MFs) and Mamdani rules related to the inputs and outputs and, implementation of the MATLAB fuzzy inference system to the Arduino Mega 2560 microcontroller. Fig. 1 shows the block diagram of the overall fuzzy logic system in this project which consists of three subsystems for the prediction of ovulation day, the FP length and the LP length. There are total of 5 inputs, 3 outputs, 63 MFs of the inputs and outputs and, 53 rules in the fuzzy logic BBT data interpretation system. Starting from the input of BBT data, then it will go through the fuzzy logic in order to be analyzed based on the set of fuzzy rules. Finally, the three fuzzy outputs of the predictions of ovulation, the length of FP and LP will be displayed in the LCD. Here, the MFs of the inputs and outputs are important to determine the rules of for the fuzzy system. Every MF has its own MF parameter value that need to be specified and it was assigned according to the Table 1.

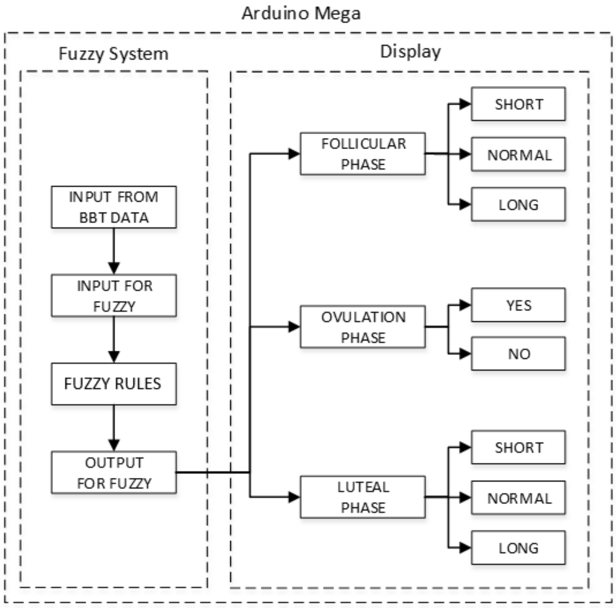

Fig. 1 Block diagram of the fuzzy logic system for BBT data interpretation

Fig. 2 shows the block diagram of the fuzzy ovulation system for the prediction of ovulation starting from three inputs of maximum different temperature between next and previous mean, MaxDiff, menstrual cycle length, MenstrualCL and range of ovulation days, RangeOvulDays, the fuzzy process of ovulation prediction based on 15 Mamdani rules and the output of ovulation prediction, OvuP. There are two MFs in MaxDiff which are less than 0.2 and more than 0.2. MenstrualCL have three MFs which are short, medium, and long. While, RangeOvulDays have six MFs which are less than day 6, day short, day between short and medium, day medium, day long, and more than day 24. Besides, there are two MFs in the output, OvuP which are not ovulate and ovulate.

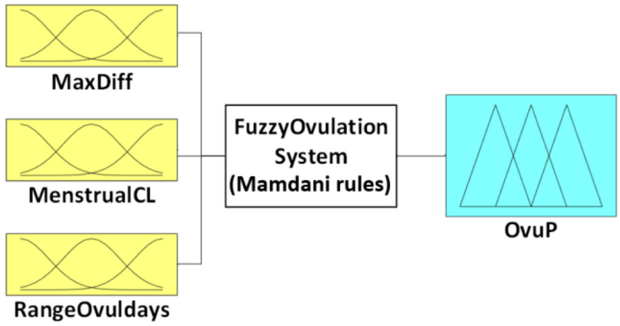

Fig. 2 The fuzzy system for the prediction of ovulation day

Fig. 3 shows the block diagram of the fuzzy system for the prediction of FP length. There are two input blocks; the follicular days, FD and the menstrual cycle length, MenstrualCL and an output of follicular phase length prediction, FPLP. There are 19 MFs in the FD and three MFs in the MenstrualCL which are short, medium, and long. While, for the output FPLP, there are three MFs which are short, normal, and long and the output is obtained based on the 19 Mamdani rules of the fuzzy follicular system with the designated MFs.

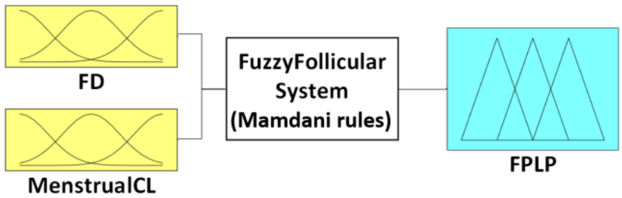

Fig. 3 Fuzzy system for the prediction of FP length

Fig. 4 shows the block diagram of the fuzzy system for the prediction of LP length. There are two input blocks, including the luteal days, LD and the menstrual cycle length, MenstrualCL and an output of luteal phase length prediction, LPLP. There are 19 MFs in the LD and three MFs in the MenstrualCL, which are short, medium, and long. Meanwhile, there are three MF in the output, LPLP which are short, normal, and long. The output is obtained based on the 19 Mamdani rules of the fuzzy luteal system with the designated MFs.

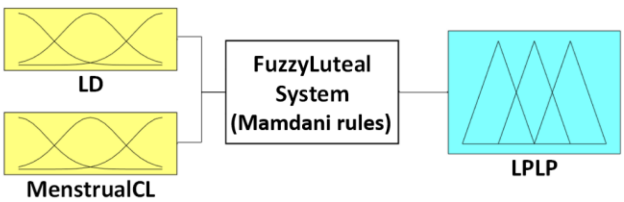

Fig. 4 Fuzzy system for the LP length

3. Results and Discussion

Fig 5 shows the prototype of the fuzzy system for BBT interpretation with a dimension of 15 cm x 6.5 cm x 5.5 cm. Based on seven BBT data (BBT 1 to BBT 7) obtained from Fertility Friend website database, performance of the developed fuzzy system for BBT data interpretation had been evaluated.

Table 2 shows the BBT interpretation results of the DO, the FP length, and LP length prediction from the seven BBT samples tested in the fuzzy system and their actual values obtained from the Fertility Friend website for comparison.

Based on the comparison between the prediction and the actual values, they have shown the same results for the BBT 1 until BBT 5, given that the BBT 1, BBT 2 and BBT 5 have a medium cycle length of 29, 32 and 28 days, respectively. While of, the BBT 3 has 34 days of a long cycle length and the BBT 4 has 22 days (short) of a short cycle length.

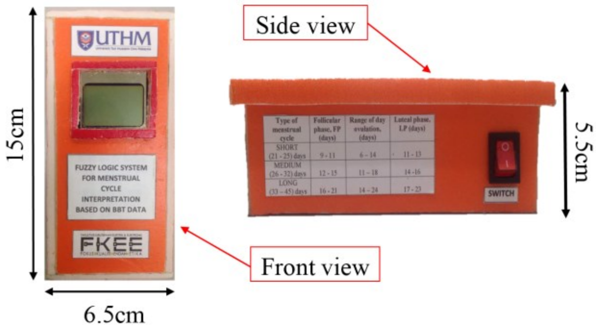

Fig. 5 Dimension of the BBT interpretation prototype

Table 2 Confusion matrix for fuzzy ovulation system

Sample of BBT data	Day of Ovulation, *DO*		Follicular Days, *FD*		Luteal Day, *LD*	
	Prediction	Actual	Prediction	Actual	Prediction	Actual
BBT 1	DO = Day-14	DO = Day-14	FD = 13 Days (Normal)	FD = 13 Days (Normal)	LD = 15 Days (Normal)	LD = 15 Days (Normal)
BBT 2	DO = Day-18	DO = Day-18	FD = 17 Days (Long)	FD = 17 Days (Long)	LD = 14 Days (Normal)	LD = 14 Days (Normal)
BBT 3	DO = Day-22	DO = Day-22	FD = 21 Days (Normal)	FD = 21 Days (Normal)	LD = 12 Days (Short)	LD = 12 Days (Short)
BBT 4	DO = Day-8	DO = Day-8	FD = 7 Days (Short)	FD = 7 Days (Short)	LD = 14 Days (Long)	LD = 14 Days (Long)
BBT 5	DO = Day-15	DO = Day-15	FD = 14 Days (Normal)	FD = 14 Days (Normal)	LD = 13 Days (Short)	LD = 13 Days (Short)
BBT 6	DO = NO	DO = Day-13	FD = NO	FD = 12 Days (Normal)	LD = NO	LD = 11 Days (Normal)
BBT 7	DO = Day-18	DO = Day-53	FD = 17 Days (Long)	FD = 52 Days (Long)	LD = 52 Days (Long)	LD = 17 Days (Long)

However, there are differences between the prediction and the actual value for the sample of the BBT 6 and the BBT 7. Here, the BBT 6 has 24 days (short) of a short cycle length and the BBT 7 has 70 days of a long cycle length because of Polycystic Ovary Syndrome, PCOS problem. The interpretation the BBT 6 had shown an inaccurate result of the DO prediction with no ovulation. Thus, the FP and the luteal LP lengths cannot be predicted. While, the actual value of the DO for BBT 6 is at day-13 with the FP and LP lengths are 12 and 11 days. For the results of the BBT 7, the DO occurrence, the FP length and the LP length were incorrectly predicted as day-18, 17 days (long), and 52 (long), respectively. While, the actual value of the DO, the FP length and the LP length are day-53, 52 days (long), and 17 (long), respectively.

The incorrect interpretation of the BBT 6 and the BBT 7 is generally caused from an imperfect designation of the fuzzy rules in tracking the ovulation day since the ovulation occurrence has been predicted as positive only by a single rule which is when a maximum different between two adjacent temperatures is higher than 0.2°C. Based on the BBT 6, the maximum temperature difference is only 0.15°C, thus the ovulation occurrence had been inaccurately predicted as negative. Meanwhile, for the BBT 7, the system had incorrectly predicted the DO earlier at day-18 since the temperature difference with more than 0.2 °C is happened two time; at day-18 and day-53. Thus, based on only the single rule, the correct ovulation day which is at day-53 was cannot be predicted. Table 3 shows the confusion matrix for an accuracy performance evaluation of the fuzzy ovulation system with the total number of seven tested data, *n*. The tested data are based on the actual positive BBT 1 to the BBT 7, where the case when the day of the ovulation occurrence was correctly predicted is labeled as positive and vice versa. Here, true positive, TP is determined by the number of accurate predicted positive data and false positive, FP is determined by the number of inaccurate predicted positive data. Meanwhile, true negative, TN is determined by the number of accurate predicted negative data and false negative, FN is determined by the number of the inaccurate predicted negative data [11].

As shown in Table 3, the fuzzy system had successfully predicted five data as TP, while the other two were predicted as FN. Moreover, zero data had been predicted as TN and FP, since there was no actual negative data tested. According to equation (4), the fuzzy system achieved 71.43 % accuracy in predicting the ovulation occurrence with a correct ovulation day.

Table 3 Confusion matrix for fuzzy ovulation system

n = 7	**Predicted: Positive**	**Predicted : Negative**	
Actual: Positive	TP = 5	FN = 2	7
Actual: Negative	FP = 0	TN = 0	0
	5	2	

$$\text{Accuracy} = \frac{\text{TP}+\text{TN}}{\text{TOTAL}} \times 100\% \quad (4)$$

TP : True positives
TN : True negatives
FP : False positives
FN : False negatives

4. Conclusion

As a conclusion, the development of the fuzzy system for BBT data interpretation had been done towards helping women to interpret their menstrual cycle easily in a portable manner by implementing it on a microcontroller based system using Arduino Mega 2560. The accuracy of the fuzzy system was optimally achieved at 71.43% in interpreting the BBT data for the ovulation day with the FP and LP lengths. Therefore, this system could help women to understand better their menstrual cycles in order to improve and raise awareness on their unique women's health. However, this project needs to be improved in terms of the rules and MF parameter values to increase the system accuracy [12]. Besides, it should be utilized with the internet of things (IoT) and integrated with a temperature measurement system to make better use of this project.

5. Acknowledgement

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