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Self-Isolation Monitoring Of Covid-19 Patients Using Fuzzy Inference System-Tsukamoto

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Abstract

In self-isolation of Covid-19 patients, it is very important to carry out regular condition checks. Currently, the examination of severity of patien's condition can be carried out by the patient himself online with the tools as measurement provided by public health center, and the data can be monitored by medic team. Several applications for monitoring the daily condition of Covid-19 patients have been developed but the parameters used in the monitoring application are not standardized and the accuracy of the application is unknown. This study aims to develop a Covid-19 patient monitoring application using more complete and accurate parameters. The input parameters used are body temperature, O2 saturation, pulse rate, and respiratory rate. The output is the level of the Covid-19 patient's condition which is divided into mild, moderate, and severe, as well as information on the actions that must be taken. This research uses the Fuzzy Inference System-Tsukamoto method. The test results between the system output and expert testing related to the condition of Covid-19 patients show that this self-checking application for monitoring has an accuracy of 95%, meaning that the monitoring system with Tsukamoto Fuzzy Inference System has a high similarity between the actual measurement results made by medical staff with the result of the system, so it is feasible to use.
Keywords: *Self-isolation; Fuzzy; Tsukamoto; Covid-19.*

Abstrak

Dalam isolasi mandiri pasien Covid-19, sangat penting untuk melakukan pemeriksaan kondisi secara rutin. Saat ini, pemeriksaan level keparahan kondisi pasien Covid-19 dapat dilakukan oleh pasien sendiri secara online dengan bantuan alat ukur yang disediakan oleh Puskesmas, dan datanya dapat dipantau oleh tim medis. Beberapa aplikasi pemantauan kondisi harian pasien Covid-19 telah dikembangkan tetapi parameter yang digunakan dalam aplikasi pemantauan tidak terstandarisasi dan keakuratan aplikasi tidak diketahui. Penelitian ini bertujuan untuk mengembangkan aplikasi monitoring pasien Covid-19 dengan menggunakan parameter yang lebih lengkap dan akurat. Parameter input yang digunakan adalah suhu tubuh, saturasi O2, frekuensi nadi, dan frekuensi pernapasan. Outputnya adalah tingkat kondisi pasien Covid-19 yang terbagi menjadi ringan, sedang, dan berat, serta informasi tindakan yang harus dilakukan. Penelitian ini menggunakan metode Fuzzy Inference System-Tsukamoto. Hasil pengujian antara keluaran sistem dan pengujian pakar terkait kondisi pasien Covid-19 menunjukkan bahwa aplikasi self-checking untuk monitoring ini memiliki akurasi sebesar 95% artinya bahwa system monitoring dengan Fuzzy Inference System Tsukamoto memiliki kesamaan hasil yang tinggi antara hasil pengukuran sebenarnya yang dilakukan tenaga medis dengan hasil dari system, sehingga layak untuk digunakan.
Kata Kunci: *Self-Isolation, Fuzzy; Tsukamoto; Covid-19.*

1. INTRODUCTION

The world is currently still dealing with the Covid-19 disease. WHO has declared Covid-19 a world pandemic. The Indonesian government has also designated Covid-19 as a state of emergency for a disease outbreak [1]. Of the total cases, 20% of infected patients require hospitalization, while the other 80% are self-quarantined and self-isolated [2].

This self-isolation involves the Public Health Center, known as Puskesmas. The main task of the Puskesmas is to ensure that confirmed Covid-19 patients undergo isolation and coordinate with Puskesmas officers to carry out daily monitoring if the patient is self-isolating [2]. This daily monitoring will be difficult to do if Puskesmas officers have to visit patients, therefore, self-screening of the condition of Covid-19 patients with online applications and centralized data is highly recommended [2], [3].

Lack of key objective parameters when monitoring patients can cause emergencies to be delayed [4]. That is why, parameters are very important in checking the condition of Covid-19 patients. The main parameters of the Covid-19 self-screening during self-isolation have four inputs, namely body temperature, oxygen (O_2) saturation, pulse frequency, and respiratory rate [5], [6]

Several Covid-19 Monitoring Applications for Self-Isolation have been developed but use incomplete parameters and could not provide recommendation. First, an IoT-based monitoring application with only two parameters, temperature and oxygen [7], [8]. Another application built uses three parameters, namely temperature, O_2 saturation and pulse rate [9]. From the applications that have been made, the accuracies of the applications are also unknown, yet in the medical world, accuracy is very important. Some applications that use incomplete parameter and do not produce the recommendation have been done in [10], [11].

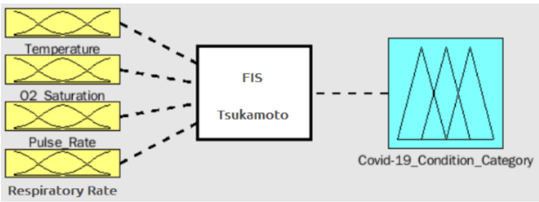
This study aims to develop a Covid-19 Monitoring Application for Self-Isolation using more complete and accurate parameters. The proposed system uses four input parameters: temperature, O_2 saturation, pulse rate, and respiratory rate [5], [6]. In this condition, patients who have confirmed positive Covid-19 will be given measuring tools to help input the data variables into the system. The output system is the categories of patient conditions: mild, moderate, and severe, as well as information on actions to be taken. This research uses the Fuzzy Inference System (FIS)-Tsukamoto method. This method gives more optimal results compared to the Fuzzy Inference System-Sugeno [12]. FIS-Tsukamoto also suitable for the use of real-world problems which are mostly non-binary and non-linear. This method can map input into output without ignoring the existing factors and has tolerance for existing data [13].

2. METHODOLOGY

The COVID-19 Monitoring System was developed using the Fuzzy Inference System (FIS)-Tsukamoto. This method consists of three main components, namely the fuzzification, inference and defuzzification processes which produce the recommendation outputs shown in Picture 1 [13] [14], [15], [16].

Picture 1. Fuzzy Components [13]

This system has four input variables, namely body temperature, O_2 saturation, pulse rate, and respiratory rate, including symptoms experienced by patients during self-isolation as additional information for Puskesmas. The results of the patient's input will be processed using FIS Tsukamoto and result the categories of patient conditions, namely mild, moderate, or severe. The process is shown in Picture 2.

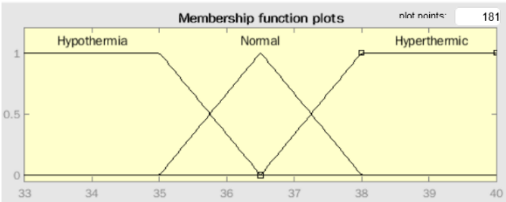


Picture 2. Fuzzy Inference Tsukamoto

A. Fuzzyfication Process

Fuzzyfication is a process to change the input that has firm values (crips) into fuzzy variables (linguistic variables) using membership functions [15]. The input variables in this system are body temperature, O2 saturation, pulse rate, and respiratory rate.

The fuzzy sets of temperature variable are divided into three, namely hypothermia (≤35 C), normal (35.1 to 37.9 C), and hyperthermic (≥ 38 C) [12]. This sets are used as a reference in the formation of the fuzzy membership function for temperature variable. The fuzzy sets of temperature variable are shown in Picture 3.



Picture 3. The fuzzy sets of temperature variable

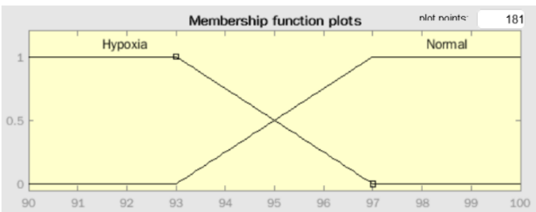
The membership function for each body temperature set is formulated in equations (1), (2) and (3).

$$\mu_{hypothermia}[x] = \begin{cases} 1, & x < 35 \\ \frac{36,5 - x}{1,5}, & 35 \le x \le 36,5 \\ 0, & x > 36,5 \end{cases} \quad (1)$$

$$\mu_{normal}[x] = \begin{cases} 0, & x < 35 \text{ or } x > 38 \\ \frac{x-35}{1,5}, & 35 \le x \le 36,5 \\ \frac{38-x}{1,5}, & 36,5 \le x \le 38 \end{cases} \quad (2)$$

$$\mu_{hyperthermic}[x] = \begin{cases} 0, & x < 36,5 \\ \frac{x-36,5}{1,5}, & 36,5 \le x \le 38 \\ 1, & x > 38 \end{cases} \quad (3)$$

The fuzzy sets of O_2 saturation (Sp02) are divided into normal (95 to 100%) and hypoxia (<95%) [17], in the case of Covid-19 clinical signs of pneumonia if you have Sp02 <93% [13]. This sets are used as a reference in the formation of the fuzzy membership function for O_2 saturation variable. The fuzzy sets of O_2 saturation variable are shown in Picture 4.



Picture 4. The fuzzy sets of O_2 saturation variable

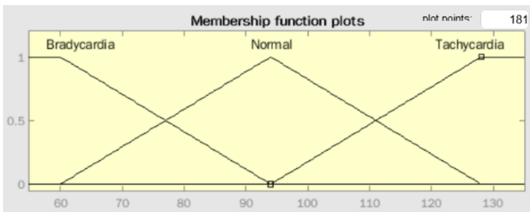
The membership function for each O_2 saturation set is formulated in equations (4) dan (5).

$$\mu_{hypoxsia}[x] = \begin{cases} 1, & x < 93 \\ \frac{97 - x}{4}, & 93 \le x \le 97 \\ 0, & x > 97 \end{cases} \quad (4)$$

$$\mu_{normal}[x] = \begin{cases} 0, & x < 93 \\ \frac{x-93}{4}, & 93 \le x \le 97 \\ 1, & x > 97 \end{cases} \quad (5)$$

The fuzzy sets of human pulse frequency based on age are divided into 3, namely infants aged < 1 year, children aged 1 to 17 years, and adults aged over 18 years [17]. The aged used in this study is limited to starting from the age of 5 children, so that the respiratory classification used is children aged 5 to 17 years, and adults aged over 18 years.

The fuzzy sets of the pulse frequency of children aged 1 to 17 years is divided into 3, namely bradycardia (< 70 beats per minute), normal (70 – 120 times per minute), and tachycardia (>120 beats per minute). While the classification of the pulse frequency of adults over 18 years is divided into 3, namely bradycardia (<60 beats per minute), normal (60 – 100 times per minute), and tachycardia (> 100 beats per minute). In the case of Covid-19, the clinical sign of an adult pulse rate is more than 125 beats per minute [18]. This fuzzy sets are used as a reference in the formation of the fuzzy membership function for the pulse frequency input variable as shown in Picture 5 and Picture 6.



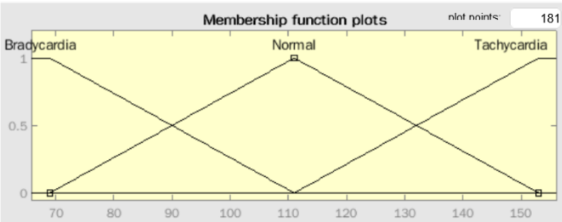
Picture 5. The Fuzzy sets of pulse rate variable for adults aged over 18 years

The membership function for pulse rate variable for adults aged over 18 years is formulated in equations (6), (7) and (8).

$$\mu_{bradycardi}[x] = \begin{cases} 1, & x < 60 \\ \frac{94 - x}{34}, & 60 \le x \le 94 \\ 0, & x > 94 \end{cases} \quad (6)$$

$$\mu_{normal}[x] = \begin{cases} 0, & x < 60 \text{ or } x > 128 \\ \frac{x-60}{34}, & 60 \le x \le 94 \\ \frac{128-x}{34}, & 94 \le x \le 128 \end{cases} \quad (7)$$

$$\mu_{tachycardi}[x] = \begin{cases} 0, & x < 94 \\ \frac{x-94}{34}, & 94 \le x \le 128 \\ 1, & x > 128 \end{cases} \quad (8)$$



Picture 6. Fuzzy set of pulse rate variable for aged between 5 and 17

The membership function for pulse rate variable for children aged between 5 and 17 years is formulated in equations (9), (10) dan (11).

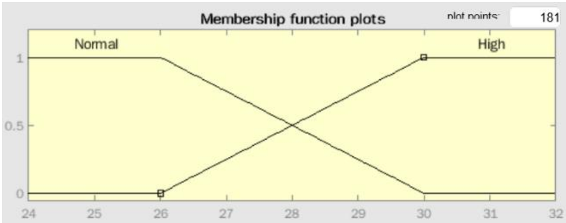
$$\mu_{bradycardia}[x] = \begin{cases} 1, & x < 69 \\ \frac{111 - x}{42}, & 69 \le x \le 111 \\ 0, & x > 111 \end{cases} \quad (9)$$

$$\mu_{normal}[x] = \begin{cases} 0, & x<69 \text{ or } x>153 \\ \frac{x-69}{42}, & 69 \le x \le 111 \\ \frac{153-x}{42}, & 111 \le x \le 153 \end{cases} \quad (10)$$

$$\mu_{tachycardia}[x] = \begin{cases} 0, & x < 111 \\ \frac{x-111}{42}, & 111 \le x \le 153 \\ 1, & x > 153 \end{cases} \quad (11)$$

The fuzzy sets of human respiratory rate based on age are divided into 4, namely age < 2 months, age 2 months to 11 months, age 1 year to 5 years, and age over 5 years [12]. The aged used in this study is limited to starting from the age of 5.

The fuzzy sets of respiratory rates over the age of 5 years are divided into 2, namely normal (< 30 breaths per minute) and high (30 breaths per minute) [17]. In the case of Covid-19, the clinical sign of pneumonia is if the respiratory rate is more than 30 breaths per minute [18]. This sets are used as a reference in the formation of the fuzzy membership function on the respiratory rate input variable which is shown in Picture 7.



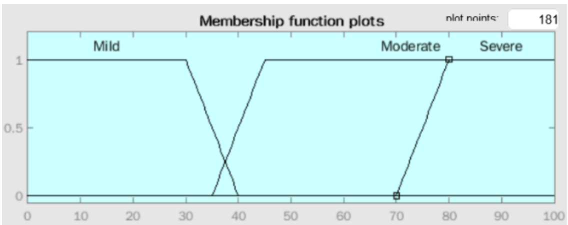
Picture 7. Fuzzy set of respiratory rate variable

The membership function for respiratory rate variable is formulated in equations (12) dan (13).

$$\mu_{Normal}[x] = \begin{cases} 1, & x < 26 \\ \frac{30 - x}{4}, & 26 \le x \le 30 \\ 0, & x > 30 \end{cases} \quad (12)$$

$$\mu_{high}[x] = \begin{cases} 0, & x < 26 \\ \frac{x-26}{4}, & 26 \le x \le 30 \\ 1, & x > 30 \end{cases} \quad (13)$$

The output variable from this self-screening is in the category of Covid-19 patient's condition which is divided into mild, moderate, and severe. The resulting output is obtained by making the membership function range between 0 and 100. Mild condition have an interval of 0 – 40; moderate condition have an interval of 35 – 70; and severe condition have an interval of 70 – 100. Membership function of COVID-19 condition is shown in Picture 8.



Picture 8. The fuzzy sets of output variable

B. Inference System

Inference system is a process to convert input variable into fuzzy output by following ruled based or IF-THEN rules that have been set [15]. The total rule based in this system are108 rules, but only 29 rules that are used after adjusted by the experties. Examples of rules used in this study are shown in Table 1.

Table 1: Example of Ruled Based

No.	Rule
[R13]	IF Normal Temperature AND Normal O_2 Saturation AND Bradycardia Pulse Frequency AND Normal Breathing Rate THEN Mild Covid Condition
[R25]	IF Hyperthermia Temperature AND Normal O_2 Saturation AND Bradycardia Pulse Frequency AND Normal Breathing Rate THEN Mild Covid Condition
[R64]	IF Hyperthermia Temperature AND Normal O_2 Saturation AND Normal Heart Rate AND High Respiratory Rate THEN Moderate Covid Condition
[R66]	IF Hyperthermia Temperature AND Normal O_2 Saturation AND Tachycardia Pulse Rate AND High Respiratory Rate THEN Moderate Covid Condition
[R104]	IF Hyperthermia Temperature AND Hypoxia O_2 Saturation AND Bradycardia Pulse Rate AND High Respiratory Rate THEN Severe Covid Condition

The next step is to find the value of α-predicate using the Smallest of Maximum (SOM) method. The value of α-predicate is obtained from each rule [11], here is an example of α-predicate used:

[R] IF Normal Temperature AND Normal O_2 Saturation AND Bradycardia Pulse Rate AND Normal Breathing Rate THEN Mild Covid Condition

α-predikat = $\mu_{normal} \cap \mu_{normal} \cap \mu_{bradycardia} \cap \mu_{normal}$

α-predikat = MIN (µx1, µx2, µx3, µx4)

Next is to find the value of z in each rule with the formula

α-predikat = $\frac{z-a}{b-a}$

Z = (α-predikat * b) – (α-predikat * a) + a

where the values of a and b are membership functions in each output set of each rule.

C. Defuzzifikasi

Defuzzifikasi is a process to change the fuzzy output in the form of linguistic variables obtained from the inference system into firm values (crips). The results of the inference are then processed using a weighted average [11]

$$Z = \frac{\alpha_1 z_1 + \alpha_2 z_2 + \cdots + \alpha_m z_n}{\alpha_1 + \alpha_2 + \cdots + \alpha_m}$$

Determination of alternative conclusions from Covid-19 symptoms by determining whether the result value (Z) is in the range of mild, moderate, or severe symptoms.

3. RESULT AND DISCUSSION

A. Case Study

The data used for the test was obtained from the results of monitoring Covid-19 patients under the supervision of the UPT Puskesmas Ngorikan Surakarta. When a patient performs an independent health check with this application, the patient enters data on body temperature, O_2 saturation, pulse rate, and respiratory rate. Here's the example of how to calculate FIS-Tsukamoto:

Age = 20 Years
Temperature = 35.8 oC
O_2 saturation = 99%
Pulse rate = 70 beats per minute
Respiratory rate = 18 breaths per minute

From the input data, the patient then enters the Fuzzification process, with the following calculations:

For body temperature = 35.8, the results obtained are:

$\mu_{hyphotermia}[x]$ = $\frac{36,5 - 35,8}{1,5}$ = 0,47

$\mu_{normal}[x]$ = $\frac{35,8 - 35}{1,5}$ = 0, 53

$\mu_{hypertermic}[x]$ = 0

For O2 saturation = 99% then the results are:

$\mu_{hypoxsia}[x]$ = 0

$\mu_{normal}[x]$ = 1

For pulse frequency = 70 (because the patient is 20 years old, then using an adult pulse rate curve) the results obtained are:

$\mu_{bradychardia}[x]$ $= \frac{94-70}{34} = 0,7$
$\mu_{normal}[x]$ $= \frac{70-60}{34} = 0,3$
$\mu_{tachycardia}[x]$ $= 0$

For respiratory rate = 18 then the results are:
$\mu_{normal}[x]$ $= 1$
$\mu_{high}[x]$ $= 0$

The next step is the inference system process by looking for the α-predicate value according to the rules used, namely:

[R1] IF Hypothermic Temperature AND Normal O_2 Saturation AND Bradycardia Pulse Rate AND Normal Respiratory Rate THEN Mild Covid Condition

α-predikat$_1$ $= \mu_{hypotermic} \cap \mu_{normal} \cap \mu_{bradycardia} \cap \mu_{normal}$
= MIN (µx1, µx2, µx3, µx4)
= MIN (0.47; 1; 0.7; 1)
= 0.47

[R3] IF Hypothermic Temperature AND Normal O_2 Saturation AND Normal Pulse Rate AND Normal Respiratory Rate THEN Mild Covid Condition

α-predikat$_3$ $= \mu_{hypotermic} \cap \mu_{normal} \cap \mu_{normal} \cap \mu_{normal}$
= MIN (0.47; 1; 0.3; 1)
= 0.3

[R13] IF Normal Temperature AND Normal O_2 Saturation AND Bradycardia Pulse Rate AND Normal Respiratory Rate THEN Mild Covid Condition

α-predikat$_{13}$ $= \mu_{normal} \cap \mu_{normal} \cap \mu_{bradycardia} \cap \mu_{normal}$
= MIN (0.53; 1; 0.7; 1)
= 0.53

[R15] IF Normal Body Temperature AND Normal O2 Saturation AND Normal Heart Rate AND Normal Breathing Rate THEN Mild Covid Condition

α-predikat$_{15}$ $= \mu_{normal} \cap \mu_{normal} \cap \mu_{normal} \cap \mu_{normal}$
= MIN (0.53; 1; 0.3; 1)
= 0.3

[R66] IF Hyperthermia Temperature AND Normal O_2 Saturation AND Tachycardia Pulse Rate AND High Respiratory Rate THEN Moderate Covid Condition

α-predikat$_{66}$ $= \mu_{hypertermia} \cap \mu_{normal} \cap \mu_{tachicardia} \cap \mu_{Tinggi}$
= MIN (0; 1; 0, 0)
= 0

Next is to find the value of z in each rule.

Z_1 = (0.47 * 40) – (0.47 * 30) + 30 = 34,7
Z_3 = (0.3 * 40) – (0.3 * 30) + 30 = 32.9
Z_{13} = (0.53 * 40) – (0.53 * 30) + 30 = 35.3
Z_{15} = (0.3 * 40) – (0.3 * 30) + 30 = 32.9
Z_{66} = (0 * 45) – (0 * 35) + 35 = 35

The last process is defuzzification, namely:

$Z = \frac{54.4}{1.59} = 34.25$

With the result Z = 34.25, it can be concluded that the symptoms of COVID-19 experienced by the patient are in the mild category.

B. Experiment

The experiment was carried out by comparing the results of the system with the checks carried out by medical personnel (expert) at the UPT Puskesmas Nukiran. The data used are 20 samples. The summary of the test results is shown in Table 2.

Based on the test results, the calculation of the percentage of simple accuracy (%) is carried out so that the following results are obtained [18]:

Simple accuracy % $= \frac{Number\ of\ true\ results}{Number\ of\ data} \times 100\%$
$= \frac{19}{20} \times 100\%$
$= 95\%$

From the calculation results, it is known that the accuracy obtained is 95% so it can be said that the COVID-19 self-check application model can be used.

Table 2 : Experiment Data

Sample	Age	Temperature	O_2 Saturation	Pulse Rate	Respiratory Rate	System Result	Expert	State
1	Adult	36,5	99	95	28	Mild	Mild	1
2	Adult	37	99	95	31	Moderate	Moderate	1
3	Adult	37,6	98	117	27	Mild	Mild	1
4	Adult	38,1	93	95	31	Severe	Severe	1
5	Adult	37	98	70	25	Mild	Mild	1
6	Adult	36	99	80	25	Mild	Moderate	0
7	Adult	38	90	120	30	Severe	Severe	1
8	Adult	37	98	80	20	Mild	Mild	1
9	Adult	36,5	99	125	31	Moderate	Moderate	1
10	Adult	37,5	93	127	30	Severe	Severe	1
11	Child	36	100	120	28	Mild	Mild	1
12	Child	37	93	130	31	Severe	Severe	1
13	Child	35	98	130	28	Mild	Mild	1
14	Child	38,5	98	130	29	Mild	Mild	1
15	Child	37,7	99	119	31	Moderate	Moderate	1
16	Child	36,8	99	109	27	Mild	Mild	1
17	Child	37	93	120	30	Severe	Severe	1
18	Child	37,5	93	127	34	Severe	Severe	1
19	Child	37,2	100	118	19	Mild	Mild	1
20	Child	38	98	121	32	Moderate	Moderate	1

4. CONCLUSION

Fuzzy Inference System (FIS)-Tsukamoto method can be used to determine the condition of COVID-19 patients monitoring system for self-isolation. The input variables used are body temperature, O2 saturation, pulse frequency, and respiratory rate ruled based on 29 rules. The outputs are divided into three categories of COVID-19 conditions, which are mild, moderate, and severe. From the results of testing 20 data, it was obtained an accuracy value of 95%. For further work, the system will be expanded to other features using the same algorithm, that is Early Stunting Detection with the Fuzzy Tsukamoto Inference System algorithm.

STATEMENT OF APPRECIATION

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