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Fuzzy controller for adjustment of liquid level in the tank

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Abstract. This paper presents the fuzzy controller for adjustment of liquid level in the tank and presents the theoretical concepts of triangular fuzzy numbers mathematics. Using the fuzzy controller will be maintained constant the liquid level. The fuzzy controller was elaborated by authors in MatLab program and operation was simulated in SIMULINK program.

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1. Introduction

To overcome the difficulties inherent in controlling a system that is both nonlinear and time varying, a controller based on fuzzy logic was implemented. Fuzzy controllers are known for their ability to provide very good control of this type of system.

Fuzzy controllers are particularly suited to applications where it is not necessary to find the global optimum solution, that is, where a near optimum solution is sufficient.

Fuzzy controllers have their origin in the concept of fuzzy sets, which was first proposed by Zadeh in 1965. The concept was quickly expanded and there exist today extensive theories related to fuzzy sets and their corresponding fuzzy logic. While mathematically more complicated than classical sets, fuzzy sets provide a more natural representation of the world.

The notion of a group of objects, or set, is second nature to us; we are used to thinking of things as belonging, or not belonging, to a particular group. It was from this everyday experience that classical set theory was born.

According to classical set theory, there are only two possibilities; either an element x does or does not belong to a set A.

Our everyday experiences, however, tell us that the world is not so easily described.

Most often, an element x is more accurately described as only partially belonging to a set A; that is, the element x has some degree of membership in a particular set. Furthermore, the degree with which a particular element belongs to a given set may be somewhat subjective.

For example, the authors have developed a fuzzy controller for adjustment of liquid level in the tank.

The fuzzy controller used maintains constant the liquid level in tank at a same value, initially established, through adjustment of adduction and evacuation pipes valves, because in tank interfere the following perturbations:

- variation of liquid quantity at tank inlet and at outlet;
- variation of pressure in pipes;
- variation of liquid temperature;

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- variation of tank steams stress which modified the liquid volume, respectively modified the liquid level in tank.

The fuzzy controller provides at outlet modification of liquid level value at which must be finding the float with regard the system perturbations.

This value of liquid level can be:

- positive, in this case the fuzzy controller command the opening of evacuation pipe valve for can be evacuated the liquid so that liquid level come to the initial value;
- negative, in this case the fuzzy controller command the opening of adduction pipe valve for can be insert the liquid so that liquid level come to the initial value.

2. Concepts of the triangular fuzzy numbers mathematics

2.1. The defining of triangular fuzzy numbers. A triangular fuzzy numbers:

$$a = (a^s, a^m, a^d) \tag{1}$$

where a is included in F_{tr} is defined by its membership function μ_a included in $R[0,1]$ that is null on a semi-straight line $(-\infty, a^s]$, increases lineary up to value 1 on the limited segment (a^s, a^m), is unitary in point a^m, decreases lineary up to value 0 on the limited segment (a^m, a^d), and is null again on the semi-straight line $[a^d, +\infty)$:

$$\mu_a : R \to [0,1], \mu_a(x) = \begin{cases} \frac{x-a^2}{a^m-a^s} & , a^s < x < a^m \\ 1 & , x = a^m \\ \frac{a^d-x}{a^d-a^m} & , a^m < x < a^d \\ 0 & , x \nexists (a^s, a^d) \end{cases} \tag{2}$$

The intervals of strictly opposed monotonies (a^s, a^m) and (a^m, a^d) may also be punctiform if $a^s = a^m$ and/or $a^m = a^d$, simultaneously or each at a time.

If one or both intervals are punctiform, the row (rows) corresponding to the null denominater in relationship (2) is (are) omitted.

The triangularity of number is given by graphic form of the membership function μ_a, as it may be seen in figure 2.1a.

Figure 2.1a corresponds to the case in which the three definde real numbers also called basic indicators are different $(a^s < a^m < a^d)$.

Figure 2.1b and figure 2.1c correspond to the case in which two of the three basic indicators are equal $(a^s = a^m < a^d)$ and $(a^s < a^m = a^d)$ respectively, and the corresponding membership function are as follows:

$$\mu_a(x) = \begin{cases} 1 & , x = a^m \\ \frac{a^d-x}{a^d-a^m} & , a^m < x < a^d \\ 0 & , x \nexists [a^m, a^d] \end{cases} \tag{3}$$

Respectively:

$$\mu_a(x) = \begin{cases} 1 & , x = a^m \\ \frac{x-a^s}{a^m-a^s} & , a^s < x < a^m \\ 0 & , x \nexists [a^s, a^m] \end{cases} \tag{4}$$

In figure 2.1d all three basic indicators coincide $(a^s = a^m = a^d)$ and the membership function for this case is of the form:

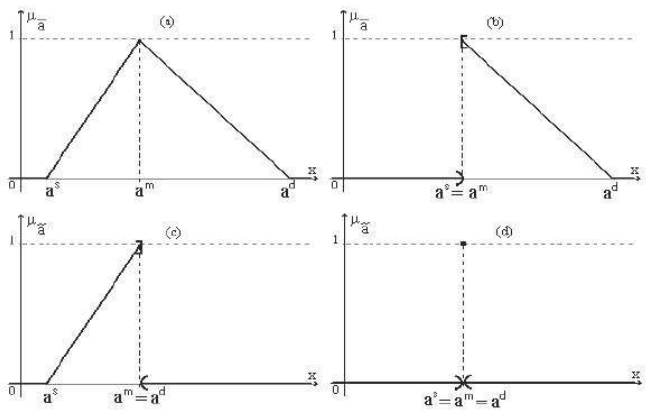

FIGURE 1. Triangular fuzzy numbers

$$\mu_a(x) = \begin{cases} 1 & , x = a^m \\ 0 & , x \neq a^m \end{cases} \tag{5}$$

Therefore, any real number $r \in R$ may be considered a degenerated (improper) triangular fuzzy number: $r = \widetilde{r} = (r, r, r) \in F_{tr}$ and its membership function will be:

$$\mu_r(x) = \begin{cases} 1 & , x = r \\ 0 & , x \neq r \end{cases} \tag{6}$$

2.2. The indicators associated to a triangular fuzzy numbers. We have already pointed out the three numerical basic indicators $a^s <\leq a^m <\leq a^d$, characteristic of a triangular fuzzy number $\widetilde{a} = a^s, a^m, a^d \in F_{tr}$.

The nucleus of the fuzzy number $\widetilde{a}$ is the set of the points in which the membership function is unitary.

In case of triangular fuzzy numbers the nucleus is punctiform and coincides with the basic indicator a^m also called *top*:

$$N(\widetilde{a}) = \{x \in R | \mu_a(x) = 1\} = a^m \tag{7}$$

The support of elementary fuzzy number $\widetilde{a} = a^s, a^m, a^d \in F_{tr}$ is the set of the points in which the membership function is strictly positive:

$$Sp(\widetilde{a}) = \{x \in R | \mu_a(x) > 0\} = (a^s, a^d) \tag{8}$$

By means of basic indicators can be found, out of which we selected the most significant ones.

The main *indicators associated* to a triangular fuzzy number $\widetilde{a} = a^s, a^m, a^d \in F_{tr}$ are:

- the top (punctiform nucleus);
- the suport ends;
- the support middle;
- the support length;
- the centre of weight (the associated real number);
- the sign;

The top or punctiform nucleus was defined by:

$$a^s = infSp(\widetilde{a}) = inf\{x \in R|\mu_a(x) > 0\} \quad (9)$$

Suport ends was defined by:

$$a^d = supSp(\widetilde{a}) = sup\{x \in R|\mu_a(x) > 0\} \quad (10)$$

Support middle was defined by:

$$sp = \frac{a^s + a^d}{2} \quad (11)$$

Support lenght was defined by:

$$L_a = a^d - a^s \geq 0 \quad (12)$$

Centre of weight was defined by:

$$a_G = \frac{a^s + 2a^m + a^d}{4} \quad (13)$$

Sign was defined by:

$$\delta_a = \begin{cases} sign(a_G) & , a_G \neq 0 \\ sign(a_N) & , a_G \neq 0 \end{cases} \quad (14)$$

Where:

$$sign(x) = \begin{cases} 1 & , x > 0 \\ -1 & , x < 0 \\ 0 & , x = 0 \end{cases} \quad (15)$$

3. Presentation of fuzzy controller

The implementation of fuzzy controller involves three stages:
- information fuzzification;
- inference operation;
- information defuzzification.

The fuzzy controller is presented in figure 3.

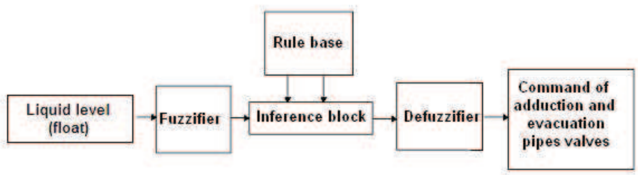

FIGURE 2. Fuzzy controller

The implementation of fuzzy controller involves three stages:
- information fuzzification;
- inference operation;
- information defuzzification.

3.1. Information fuzzification. In fuzzy control theory, an input variable is converted into a fuzzy variable by a process known as fuzzification.

Each fuzzy variable consists of a group of fuzzy sets.

The information fuzzification consists in fuzzy values assumption of input measures, respectively output in/from controller.

For example, in the adjustment of liquid level the fuzzy controller that is to be described here, the liquid level error will be one of the inputs into the fuzzy controller.

The liquid level error can be described by a group of partially overlapping fuzzy sets such as negative, zero, and positive, with each set having its own membership function.

The another inputs into the fuzzy controller in the adjustment of liquid level, that is to be described here, is the liquid level error derivative.

The liquid level error derivative can be described by a group of partially overlapping fuzzy sets such as negative, zero, and positive, with each set having its own membership function.

In this way, for any given value of the liquid level, the degree to which it belongs to each of these sets can be determined, and a control decision based on this information can be obtained.

These measures are established being determined value domains of input and output measures.

The each input or output measure to attach a set of linguistic terms. The one terms from set describe a variation interval of one measure.

The fuzzification operation will be finalised by to define of specific functions for each measure.

In this case the linguistic terms are:

- for liquid level error was attached the linguistic terms:

(1) negative;
(2) zero;
(3) positive.

The specific functions shows in figure 3.1.

- for liquid level error derivative was attached the linguistic terms:

(1) negative;
(2) zero;
(3) positive.

The specific functions shows in figure 3.1.

- for adjustment of adduction and evacuation pipes valves was attached the linguistic terms:

(1) negative;
(2) zero;
(3) positive.

The specific functions shows in figure 3.1.

3.2. Inference operation. The driving strategy have an essentially element the inference method. The inference connects the measurable input measures (fuzzy input variables, linguistic expression) of the output measure (linguistic expression).

The inference operation will be make by inference table or decision table which described the linguistic rules adopted. In table 1, figure 3.2, is presented the decision table (inference) for this case.

This table corresponding of three linguistic terms involves a nine linguistic rules, linguistic rules shows in figure 3.2.

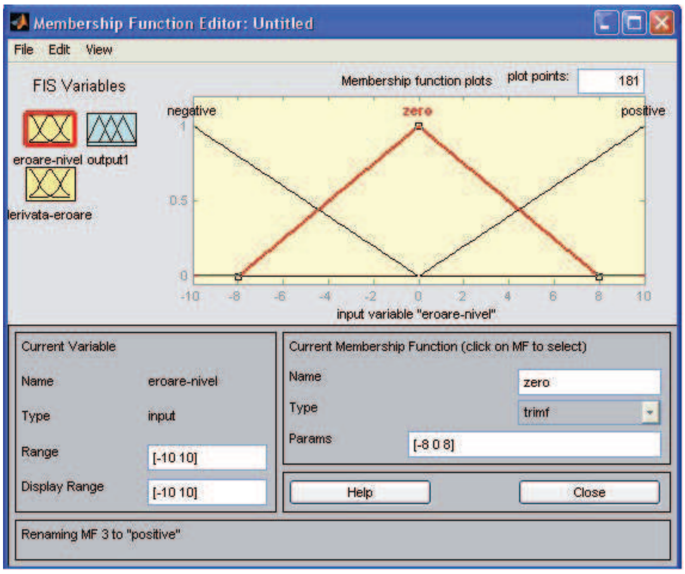

FIGURE 3. Specific functions for liquid level error

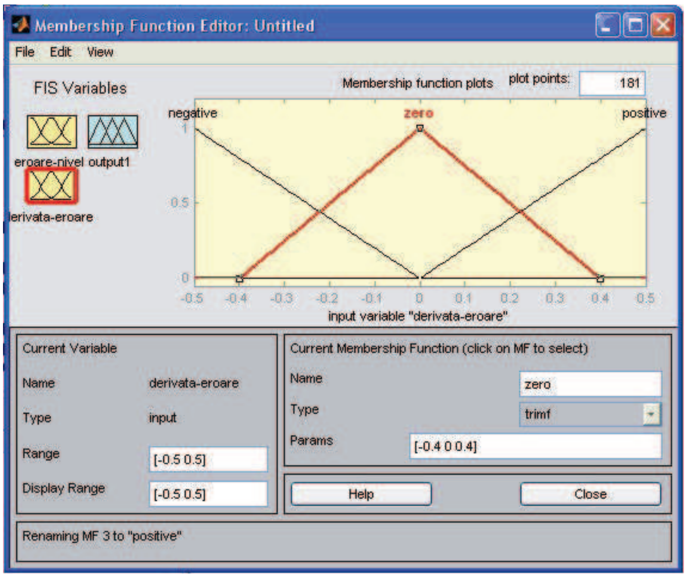

FIGURE 4. Specific functions for liquid level error derivative

For this case is used inference of Mamdani type.

3.3. Information defuzzification. Once the aggregated fuzzy set representing the fuzzy output variable has been determined, an actual crisp control decision must be made. The process of decoding the output to produce an actual value for the control signal is referred to as defuzzification.

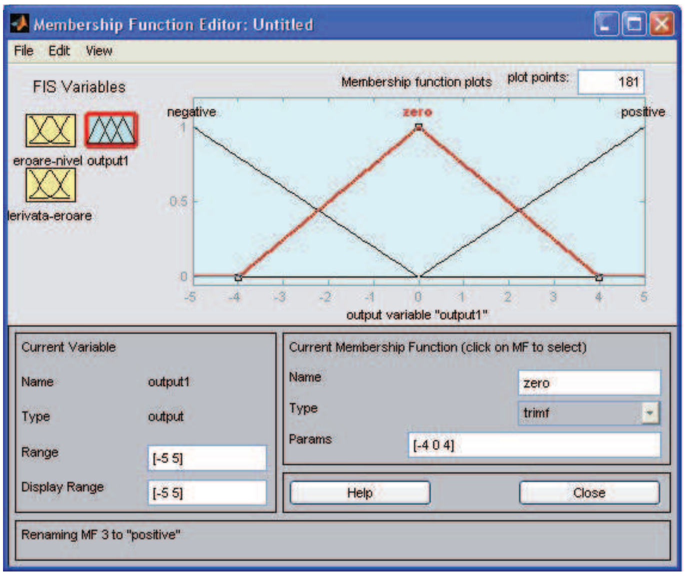

FIGURE 5. Specific functions for adjustment of adduction and evacuation pipes valves

Table 1.

Adduction and evacuation pipes valves		Liquid level error derivative		
		negative	zero	positive
Liquid level error	negative	**negative**	**negative**	**negative**
	zero	**negative**	**zero**	**positive**
	positive	**positive**	**positive**	**positive**

FIGURE 6. Decision of inference operation

For the control algorithm presented here, the primary goal was to obtain a high quality control decision in a computationally efficient manner. As a result, a novel defuzzification algorithm based on the center of gravity defuzzification technique was implemented.

This novel, approximate center of gravity defuzzification algorithm is applied. The defuzzification method used is a weight centre.

In the center of gravity defuzzification technique, the crisp value of the output is given by the center of gravity of the aggregated membership function, that is, the horizontal component of the geometric center of the aggregated fuzzy membership function.

The obtaining values from inference operation are used in defuzzification for obtaining concrete command values.

4. Results obtaining in MATLAB/SIMULINK program

On base of specific functions, an inference table and a defuzzification method was simulated through by MATLAB/SIMULINK program, the various cases which appear in practice, the obtained results shows in figure 4 and figure 4.

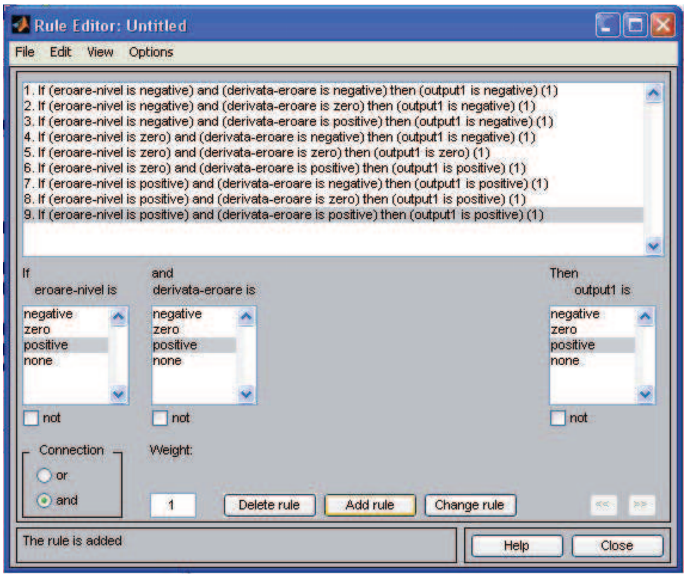

FIGURE 7. Linguistic rules

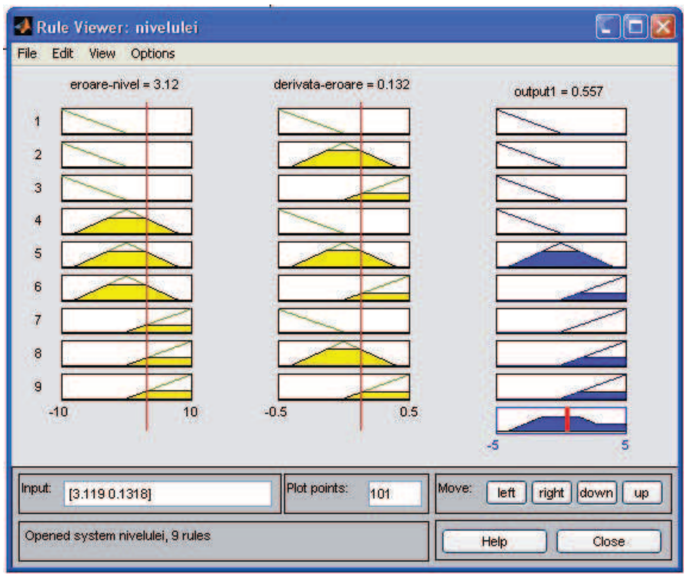

FIGURE 8. Inference at positive liquid level error and positive liquid error derivative

The SIMULINK model of adjustment liquid level in the tank is presented in figure 4 and system response is presented in figure 4.

In figure 4 it was assumed that the liquid level variation. This was modeling by applying a fuzzy controller input a signal of step type.

They also consider the transfer function of evacuation and adduction pipes valves and transfer function of process.

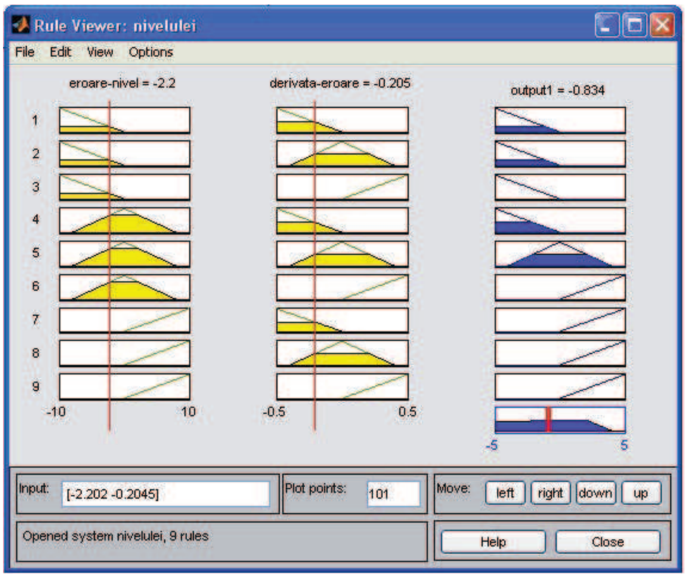

FIGURE 9. Inference at negative liquid level error and negative liquid error derivative

At output of process has provided an oscilloscope that can view the signal waveform after the adjustment process through fuzzy controller.

From figure 4, notice that the system response time is reduced using fuzzy controller is obtaining a constant value for the liquid level.

In figure 4 is presented the control surface of adjustment elements.

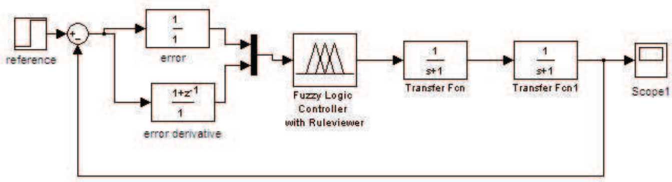

FIGURE 10. The SIMULINK model of adjustment liquid level in the tank

5. Conclusions

The fuzzy controller used maintains constant the liquid level in tank at a same value, initially established, through adjustment of adduction and evacuation pipes valves, because in tank interfere the perturbations.

Because, the fuzzy controller work with linguistic variables the liquid level will be modified with a high precision.

The fuzzy controller of system provide at output modification of liquid level hold of system perturbations.

The characteristics of the fuzzy controller that were observed during its performance validation stage were quite satisfactory.

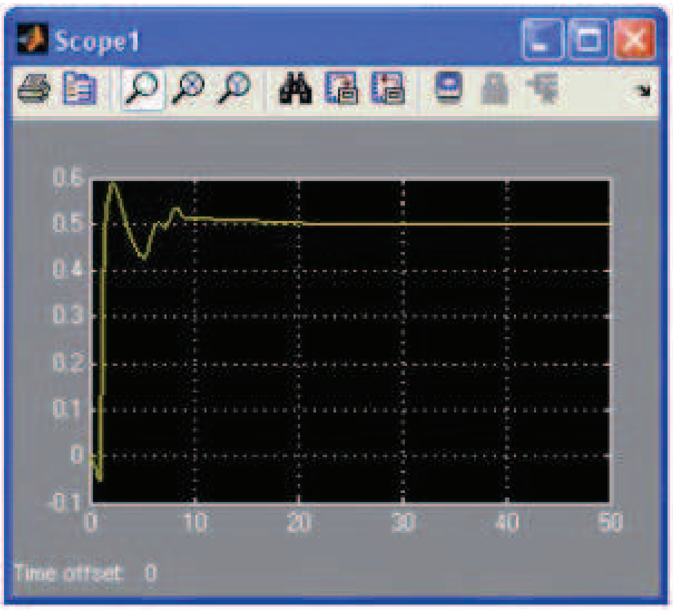

FIGURE 11. System response (wave form at output from system)

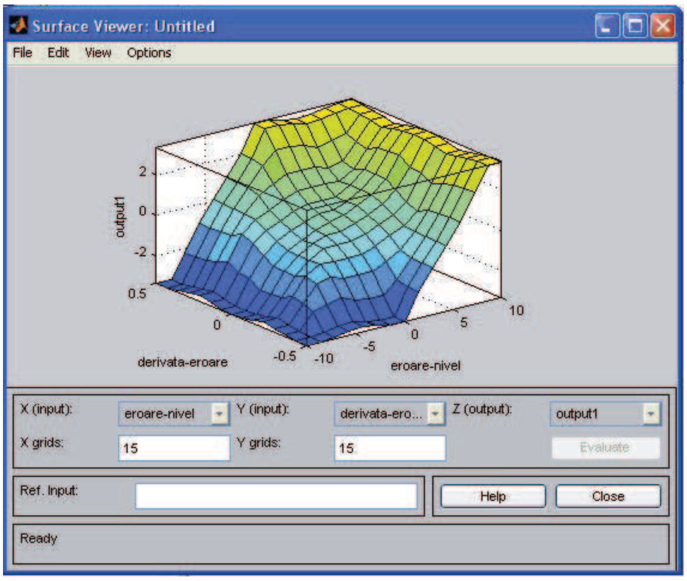

FIGURE 12. Control surface of adjustment elements

In fact, based on the results of the performance validation, it was concluded that the fuzzy controller developed was suitable for application to the control of the liquid level.

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