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To cite this article: Dwi Setiady *et al* 2019 *J. Phys.: Conf. Ser.* **1373** 012044

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Design of Automatic Braking System Using Interval Type-2 Fuzzy Logic System

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Abstract. The car braking system is a very important part of car safety. The effectiveness of Conventional braking system is strongly influenced by the ability and the driver's experience. It is very vulnerable to accidents if the driver fails to operate the braking system. Because of that, an automation of the braking system is needed that can decrease the accident's impact. The Automatic braking systems require the reasoning to manage information before making a decision that brakes or slows down. There is uncertainty in determining membership function of distance and velocity. It is difficult to determine an exact membership function. In this paper, the system use Interval type-2 fuzzy logic control that can work well in an unstructured environment and have the ability to overcome the uncertainty of information. This system will be compared with the braking system using T1FLS. The result is that the pressure on the brake pads is gradually increased. At a distance of 34 m, the pressure is at maximum value. The changes produced by the automatic braking system that uses IT2FLS increase the average pressure of 4,167% while in T1FLS system, a change in growth greater pressure by an average of 5%. In IT2FLS braking system, braking is gradually increasing smoother than T1FLS.

1. Introduction

It is undeniable that the current level of traffic accidents is still very high. Based on data compiled by the Indonesian Police, the number of traffic accident in Indonesia for the last quarter tends to increase, which is about 26,000 cases with a death toll of about 7,000 people. Based on these data, about 30% of these accidents are car accidents [1].

The braking system is one of important thing that supporting the driver's safety. The car's braking system is usually operated manually with the brake pedal. If the driver fails to break, there will be a collision or even accidents that cause damage or victim.

In recent years, a lot of research have been developed for an automatic car braking systems [2][3][4][5]. Some studies rely on mathematical modeling but the fact is that in the case of the braking system, driver behavior is strongly influenced by the experience, not the appropriate mathematical modeling [2][5]. Because of that, the system need a model that can apply human reasoning based on experience in a linguistic form that does not need to use complex mathematical models. Fuzzy logic systems are very good at applying human thinking based on experience to handle non-linear systems such as braking systems [2].



Fuzzy was first developed by Lotfi Zadeh and does not yet have the ability to handle uncertainty [6]. In this braking system, there is uncertainty information in determining a safe distance at a certain speed when braking. Safe distance is only determined according to the estimates and experiences have been obtained. conventional fuzzy is less effective in dealing with uncertainty [7].

Over the past decade, many researchers have developed Type-2 Fuzzy Logic System (T2FLS) which is an improvement from conventional fuzzy or Type-1 Fuzzy Logic System [8][9][10][11]. Type 2 has a better ability to overcome uncertainty. Compared to T1FLS, T2FLS has more parameters in representing Fuzzy set elements [7]. T2FLS has 3-dimensional functions and an uncertainty range called Footprint-Of-Uncertainty offering additional degrees of freedom to deal with various uncertainties.

Interval Type-2 Fuzzy Set (IT2FLS) is a type of type-2 Fuzzy Set that is widely used because it has lower computational complexity than general T2FS. IT2FLS has easy-to-manage computing that makes IT2FLS easy to implement [12].

This paper will discuss the braking system that applies IT2FLS methods for managing and analyzing the conditions in performing automatic braking. The purpose of this study is to test IT2FLS modeling capabilities in handling non-linear systems such as braking systems.

2. Braking System Design

2.1. Car Braking System

In this paper, the automatic braking system uses IT2FLS modeling to apply brakes when the distance between the car and obstacles is close. The output is the pressure required by the canvas brake when clamping the disk plate in Figure 1.

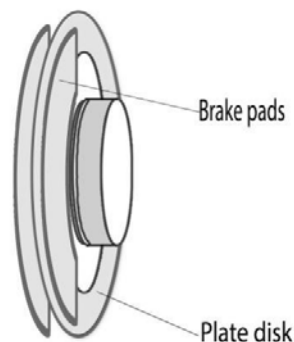


Figure 1. Illustration of the braking system mechanism

It is assumed that the pressure is 0 at minimum and 150 at the maximum. This system will be implemented using the fuzzy type-2 interval Matlab Simulink toolbox [13]. In this car's braking system, there are several parameters that have been ignored, namely engine dynamics, friction, and gravity.

2.2. System Modeling

System modeling is generally needed in the development of a system. Figure 2 shows the system process in general. Starting from the input process, the process of fuzzification, up to the results.

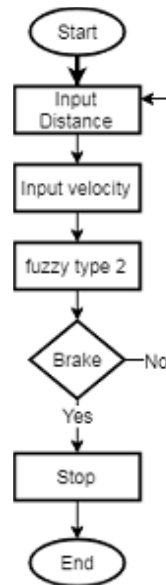


Figure 2. Block diagram Automatic braking system using IT2FLS

2.3. System planning

The method used is Grid Partition [14]. This partitioning method is often used in designing fuzzy controllers that have few variables as input to controllers. This partitioning strategy requires only a small number of MF for each input. Fuzzy models with 2 inputs and 3 MF in each input will produce 9 Fuzzy if-then rules. Rule modeling uses simple modeling, namely Takagi Sugeno Kang (TSK) model. The rule model is written in Equation (1) [15].

$$R^n: \text{If } \chi_1 \text{ is } \tilde{X}_1 \text{ and } \chi_p \text{ is } \tilde{X}_p \text{ then } y \text{ is } Y \quad (1)$$

With $(p = 1, 2, \dots, N_p)$ is IT2 FS for IT2 FLS. whereas $Y^n = [\underline{y}^n, \bar{y}^n]$ is a simple interval. This model is used $\underline{y}^n = \bar{y}^n$. In Table 1, the attribute is attached. Distance variables have 3 membership functions namely near, medium and far. Speed variable which has 3 membership functions, namely slow, medium, and fast.

Table 1. Data set attribute

Attribute	Unit	Range
Distance	Near(1), Medium(2), Far(3)	0-70(1),35-105(2),70-150(3)
Velocity	Slow(1), Medium(2), Fast(3)	0-45(1),30-70(2),50-100(3)

2.4. Design the Membership Function

Design the Membership Function After generating the rule base, the thing to do is to determine the membership function as the basis of fuzzification and defuzzification. The first thing to do is to design a membership function from T1 and become a T1 MF baseline. Furthermore, based on the MF baseline, the IT2 FOU was determined to be the presentation of randomness and uncertainty of MF data.

2.5. Designing the basis of Fuzzy Type-1 membership functions

In designing the type 1 membership function using a triangular model and trapezium with each variable has 3 parameters. Distance variable consists of near, medium, and far. Velocity variables consist of slow, medium, and fast.

2.6. Designing Footprint of Uncertainty (FOU)

This research using type 1 membership function as the basis for designing the FOU described in the previous stage. Next, determine the two fields of FOU, namely LMF and UMF. It is assumed that there is no doubt at the center point of type 1 membership function. Illustration of FOU design is shown in Figure 3.

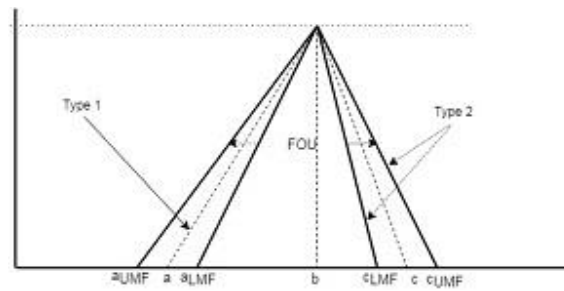


Figure 3. Design of IT2MF FOU

a_{UMF} is the left point of the UMF determined by Equation (2), ba_{UMF} is the center point of UMF with Equation (3), c_{UMF} is the right point of UMF with Equation (4), a_{LMF} is the LMF left point with Equation (5), bc_{LMF} is the LMF center point with Equation (6), c_{LMF} is the center point of LMF with Equation (7), a is the left point T1 MF, b is the center point T1 MF and c is the right point T1 MF. The results of the FOU design are shown in Figure 4 and Figure 5.

$$a_{UMF} = a - 5 \quad (2)$$

$$ba_{UMF} = b \quad (3)$$

$$c_{UMF} = c + 5 \quad (4)$$

$$a_{LMF} = a + 5 \quad (5)$$

$$bc_{LMF} = b \quad (6)$$

$$cLMF = c - 5 \quad (7)$$



Figure 4. (a) Distance membership functions at IT2FLS, (b) Velocity membership functions at IT2FLS

2.7. Interval type-2 fuzzy logic design

2.7.1. Fuzzifier

The input is a vector n crisp element $x = (x_1, x_2, \dots, x_n)^T$ in the discourse universe $x_1 \times x_2 \times \dots \times x_n$ mapped into a type-2 Fuzzy set.

2.7.2. Rule Base

The composition of the rules in set type-2 has no difference with that of type-1 shown in figure 6. The l-rule for n-input, $x_1 \in X_1, \dots, x_n \in X_n$, and m-output, $y_1 \in Y_1, \dots, y_m \in Y_m$, from type-2 Fuzzy logic systems are given in Equation (8).

$$\text{Rp: IF } x_1 \text{ is } \tilde{F}_1^p \text{ and } x_n \text{ is } \tilde{F}_n^p \text{ THEN } y \text{ is } \tilde{Y}^p \quad p=1,2,\dots,N \quad (8)$$

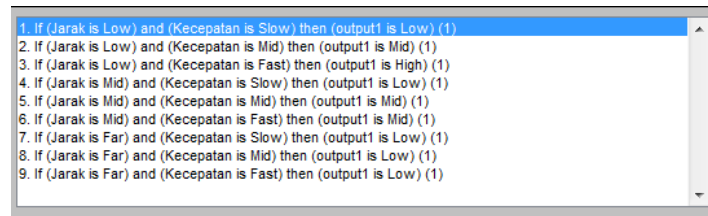


Figure 5. The Base Rule

2.7.3. Inference

The Inference is needed to combine rules and do a mapping from input to output. This is important for calculating the join \cup (union), slices \cap (intersection) the sup-star composition of type 2 relations. In this FLS, the type-2 Fuzzy set and product t-norm intervals are used, so the input and antecedent results are in the firing set $\prod_{n=1}^p \mu_{\tilde{F}_n}(x_n \equiv F^p(x'))$ is the type 2 interval set, as seen in Equation (9).

$$F^p(x') = [\underline{f}^p(x'), \bar{f}^p(x')] \equiv [\underline{f}^p, \bar{f}^p] \quad (9)$$

where

$$\underline{f}^p(x') = \underline{\mu}_{\tilde{F}_1^1}(x_1') \times \dots \times \underline{\mu}_{\tilde{F}_n^p}(x_n') \quad (10)$$

and

$$\bar{f}^p(x') = \bar{\mu}_{\tilde{F}_1^1}(x_1') \times \dots \times \bar{\mu}_{\tilde{F}_n^p}(x_n') \quad (11)$$

2.7.4. Type Reducer

The type reducer produces a type 1 Fuzzy set which will then become a defuzzification input to get the crisp value. For this research, center of sets (cos) type reduction which Y_{cos} is used is stated in Equation (12).

$$Y_{cos}(x) = \bigcup_{f^n \in f^n(x')} \frac{\sum_{n=1}^p f^n y^n}{\sum_{n=1}^p f^n} = [y_l, y_r] \quad (12)$$

with

$$y_l = \min_{k \in [1, N-1]} \frac{\sum_{n=1}^k \bar{f}^n y^n + \sum_{n=k+1}^N \underline{f}^n y^n}{\sum_{n=1}^k \bar{f}^n + \sum_{n=k+1}^N \underline{f}^n} \equiv \frac{\sum_{n=1}^L \bar{f}^n y^n + \sum_{n=L+1}^k \underline{f}^n y^n}{\sum_{n=1}^L \bar{f}^n + \sum_{n=L+1}^k \underline{f}^n} \quad (13)$$

$$y_r = \max_{k \in [1, N-1]} \frac{\sum_{n=1}^k \underline{f}^n y^n + \sum_{n=k+1}^N \bar{f}^n y^n}{\sum_{n=1}^k \underline{f}^n + \sum_{n=k+1}^N \bar{f}^n} \equiv \frac{\sum_{n=1}^R \underline{f}^n y^n + \sum_{n=R+1}^N \bar{f}^n y^n}{\sum_{n=1}^R \underline{f}^n + \sum_{n=R+1}^N \bar{f}^n} \quad (14)$$

Where L and R switch points are determined by Equation (15) and (16).

$$\underline{y}^L \leq y_l \leq \underline{y}^{L+1} \quad (15)$$

$$\bar{y}^R \leq y_r \leq \bar{y}^{R+1} \quad (16)$$

y_l and y_r Where L and R switches are determined by Equation (15) and (16) [16] (Karnik-Mendel).

2.7.5. Defuzzifier

After passing the type reducer, Y_{cos} interval value will be obtained. To defuzzify this value, only the average values of y_l and y_r are needed. The equation used is Equation (17).

$$y(x) = \frac{y_l + y_r}{2} \quad (17)$$

3. Results and Discussion

This system is implemented using Matlab. Testing is done by setting the initial speed of a car. Then place objects at a certain distance right in front of the car. This test is carried out by testing a system that applies to brake using the IT2FLS system. The car speed value is 100 km/hr. The distance to the object is 100 m. The test illustration is shown in Figure 7.

For the evaluation of the test refers to the formula for a safe distance determined by the National Police Corps, which was 3 seconds. If the speed of the car was at 100km / h, the safety distance to the object or the obstacle in front of it was 83,3 m. Based on the above calculations, braking must started at a distance of 83,3 m from the obstacle because it had passed the safe distance.

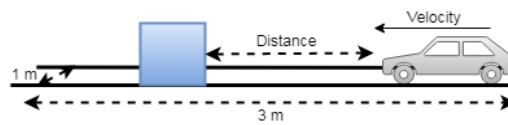


Figure 6. Illustration of Braking System Testing

Table 2. Result of The IT2FLS Bracking System

No	Distance	Preasure of Bracking System	
		IT2FLS (KM)	T1FLS
1	34	150	150
2	36	148.7	150
3	40	143.3	150
4	44	137.8	137
.	.	.	.
.	.	.	.
.	.	.	.
15	88	32.4	30
16	96	19.6	20
17	98	6.81	5
18	100	4.68	0

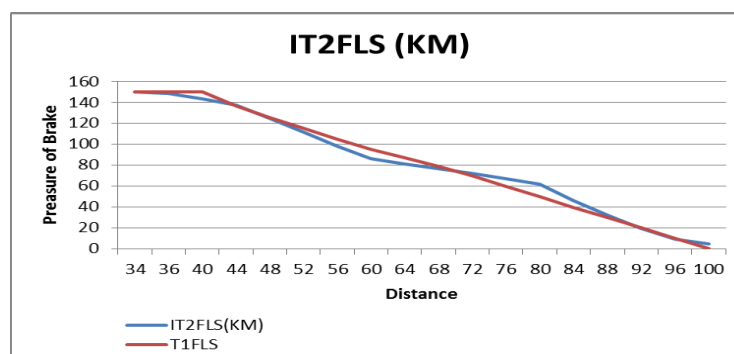


Figure 7. Result test for an automatic braking system for distance

The IT2FLS braking system would be compared to the braking system using T1FLS based on previous research [2][5]. In testing the automatic braking system, the pressure of the IT2FLS system starts at a distance of 100 m with a pressure value of 4.68. In the T1FLS, braking starts at 98 m from the obstacle with a pressure value of 5. The pressure on the canvas increases slowly along the distance

approaching. The value of IT2FLS brake pressure at a distance of 80 m is 61.6. While the T1FLS is exactly 50. At a distance of 34 m, the pressure on the IT2FLS system brake canvas is at a maximum value of 150. The pressure on the T1FLS system is at a maximum value of 40 m shown in table 2.

System testing used the same input value. Based on Figure 7, a system that uses T1FLS shows good results. This system of braking gradually increases. In systems that use T2FLS, braking is done gradually increasing smoother than T1FLS. Changes generated by the automatic braking system that uses IT2FLS increase the pressure by an average of 4.167% while the system uses T1FLS, the change in pressure increases is greater by an average of 5%.

4. CONCLUSION

In this paper, we discuss the automatic braking system using IT2FLS which has two inputs and one output. Input in the form of distance and speed while the output is in the form of pressure on the brake pads. The results show a pressure In braking system using IT2FLS smoothly increase with an average value of 4.167 %. Whereas the braking system using T1FLS has a bigger changes pressure with an average value of 5%. For further research, it can be improved by adding input and adding rules so that the system's capabilities are better.

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