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DESIGN AND ANALYSIS OF FLC AND FEEDBACK CONTROL FOR THREE FINGER GRIPPER SYSTEM

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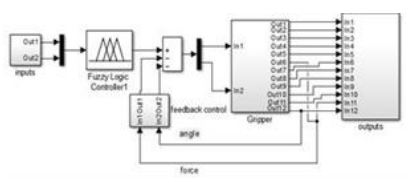
Graphical abstract



Abstract

This paper presents the fuzzy logic design and control for three finger gripper system to grasp an object. Two objectives are mainly considered in this work, which are the analysis of different membership types and the gripper performance with feedback and without feedback control to support current research findings. The comparison is also including different number of rules analysis as well as the fuzzy membership types. The simulation and analysis are carried by using MATLAB Simulink and SimMechanics toolboxes to analyze the system performance. The result shows that the gripper system with trapezoidal memberships achieved faster response and good grasp. Besides that, the proposed system with feedback has produced the best result to grasp the object with suitable torques and angles in comparison to the non-feedback gripper system.

Keywords: Fuzzy logic, feedback, non-feedback, three finger gripper, membership functions

1.0 INTRODUCTION

Nowadays, a robot is important for industry in performing any specified tasks due to its advantages such as reprogrammable and has many functions. There are many types of industrial robot such as the cylindrical, Cartesian, SCARA, articulated and spherical type robot. These robots have their own specific configurations and normally a tip is attached to the end of the robot manipulator. One of the tips which are used to lift or grasp object is a gripper. The gripper can perform various tasks that human is capable of doing but with some restrictions based on the gripper design [1, 2]. A gripper may have a minimum of two fingers or may be equipped with up to five fingers; with each type have their advantages and shortcomings. Fuzzy logic control which is one of the artificial intelligence techniques, attempts to control a system based on a linguistic control strategy. Besides, the technique does not require complex mathematical analysis and depends on some design parameters such as number of rules, membership types and the number of fuzzy sets.In general, the FLC is derived from an expert knowledge and then being transformed into automatic control strategy by taking into account some technical properties and experiences gained by the expert.

There have been some working papers that proposed fuzzy logic in robot grasping control in various applications and methods e.g. in [3, 4, 5, 6]. In [6] claims that the Fuzzy Logic offers better performance compared to PID controller not for gripper but consider in application of vehicle speed control especially when rise and the settling time consideration. Unfortunately, the effects of number of fuzzy sets for each membership are not discussed thoroughly and left with unknown results. Even though the increasing number of fuzzy sets can increase the time consumption, this has a significant effect for an application that requires high accuracy of grasping regardless of how long it takes to perform the task.

Regarding the FLC for gripper design, A. M. Zaki *et al*. [5] is one of the researchers who has analysed the gripper system using the technique. However, it is found that, they did not investigate the effect of number of fuzzy rules design. There is a possibility where through tuning process, the number of rules can be further reduced, hence, reducing the processing time. The analysis is only carried out for two fingers design which is expected to require simple control and lower cost. More fingers means a lot more computation is needed and hence increasing the time consumption when performing an operation. However, if better grasp and reliability are taken into account, then gripper with more fingers is a good choice [5]. This condition motivates this research to propose three fingers gripper design. Combination of methods has also been examined for grasping purposes. A hybrid Neuro-FLC performance for gripper was also described in [8]. Even though the design includes the Neural Networks technique, they expressed that with proper design rule, the result can be better. In addition, the authors have highlighted some basic guidelines for gripper design based on previous findings. Those steps are referred to during our gripper design.

Previous work [9] has analyzed a gripper system but without the existence of a feedback configuration. Similar system is being analyzed in this paper to examine the behavior of having a feedback system. Regarding the membership types, [10] appealed that the triangular membership is missing of linguistic clarification in comparison to Gaussian approach. Hence, the Gaussian membership could achieve better results than the other types of membership. However, the trapezoidal type is not included in their analysis. In fact, the study is lacking of the rule that must be set in Fuzzy Logic and the analyses about that are not considered. Regarding the three finger design, one of the researchers have simulated and designed three fingers for gross motion which includes fine motion and finger positioning into approximate outline by classical PD control with a force feedback. In order to grasp a specific object, each finger needs specific forces to control the gripper especially for grasping fragile and delicate object [11]. The feedback loop aids the gripper for better grasping. K. Telegenov *et al*. [12] have proposed an open-loop optimal control method for creating the optimal trajectory of the flexible robotic arms in point-to-point motion based on Pontryagin's minimum principle. Even though the results are promising, the closed-loop control still needs further analysis to determine its capability. Hence this paper attempts to analyse the consequences of having the feedback control system for a gripper.

In this paper, three different membership functions are considered to determine the best performance for the grasping system. The design considers a gripper system that has to grasp an object of 5kg. Three aspects are observed which includes the membership types, number of fuzzy rules and the design with feedback control. In accordance to this objective, the triangular membership function is easier and faster calculation time than others two but, Gaussian membership function could offer best solution when firmer grasp are considered [9].

This paper is organized as follow. Section 2 presents the gripper system design based on Matlab Simulink and SimMechanics toolboxes. This is followed by the FLC development for the proposed gripper system. Section 3 describes the simulation and analysis and finally section 4 concludes the paper.

2.0 METHODOLOGY

2.1 Gripper Design

The work is focused on three gripper weighting about 3.6 kg while the mass applied in inertia is negative and positive in values. The design parameters are based on the guidelines given by A. Krishnaraju *et al*. [1], A. M. Zaki *et al*. [5] and others [12]. These values are considered based on the motion of the finger in x, y and z axis directions. A gripper with six bodies in SimMechanics is designed with three fingers consisting of thumb, middle and index fingers respectively. Besides, based on [15] were concentrated on aspects grasping systems by position of grasp points with taken from center of mass of the objects.

Table 1 shows the information about weight, inertia and sizes for each finger of the gripper. Given the gripper properties, the design for three finger gripper in MATLAB SimMechanics is illustrated in Figure 1. The first, third and fifth bodies are 0.8kg in weight respectively that makes the upper body of the fingers. While the second, fourth and sixth bodies are all weight about 0.4 kg each. Recognized that, the mass of inertia for thumb is different than the two other fingers because of the operation and force applied is different. This work attempts to model the same properties as human thumb. This gripper are designed such that it is connected to each other and do not have palm or based and the body length is designed to be 7cm and 8.5cm for the second, fourth, sixth bodies and first, third and fifth bodies respectively.

Table 1 Information of three finger gripper

	Body	Mass (kg)	Mass of Inertia (kg)	Size of length (cm)
Thumb	First	0.8	-23	8.5
	Second	0.4	27	7
Middle	Third	0.8	28	8.5
	Fourth	0.4	-50	7
	Fifth	0.8	28	8.5
Index	Sixth	0.4	-50	7

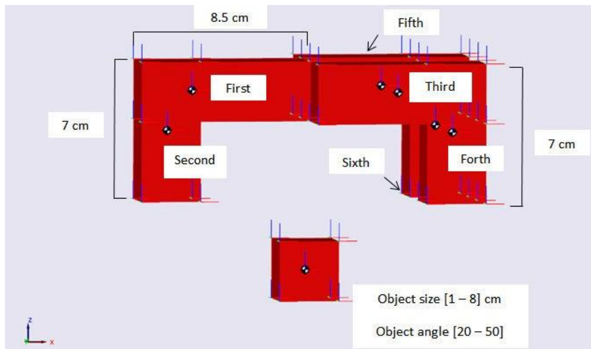


Figure 1 Three fingered gripper design

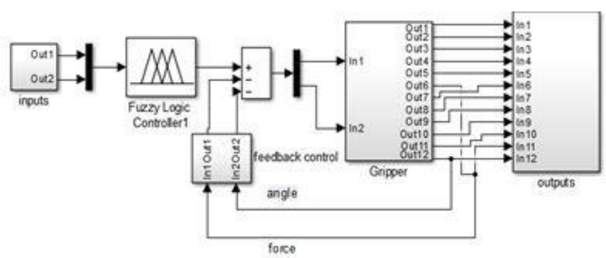


Figure 2 Feedback control system

The proposed system with a FLC is built to take into consideration about both the input and output. By this technique, the performance can be evaluated accordingly to analyze the outcomes for different fuzzy rules, number of fuzzy sets and the type of memberships. To model the gripper, two inputs and two outputs are referred. The inputs are the object size and the angle of the second, fourth and sixth angles of the gripper bodies. The outputs are the angle of each finger and the expected torques to be applied to the object when grasping.

There are various challenging issues found for the gripper about how they grasp various types of objects. Inspired by human fingers behavior, Koustoumpardis *et al*. [13] has designed a low cost 3-finger gripper to grasp fabrics. The specifications of dimensions, tendon's force, pulleys and motors are described with the kinematic and static analysis to assess the gripper ability. The authors have proved that applying an intelligent control technique is significant in higher level applications especially when different types of grasping procedures are expected for at least in the case of grasping fabric.

As for this project, each of the fingers has two degree of freedoms (D.O.Fs). The analysis mainly focuses on two main objectives. The first one is to determine the advantages of having FLC in a gripper. This is then followed by the motivation to evaluate the effects of a feedback system into the proposed system. The simulation time is fixed to observe the capabilities of the proposed design in comparison to the system without FLC and feedback loop. Figure 2 shows the feedback control system which includes some designed gains for better grasping. These two main goals will be the contributions for this research as well as the new approach of design using MATLAB SimMechanics toolboxes for a gripper system.

2.2 Fuzzy Logic Controller Design

In order to make the gripper grasp objects that able to imitate human actions, FLC is used to process the input data appropriately in controlling the gripper finger motions. In FLC, there are two types of methods to be chosen which is Mamdani method or the Sugeno method. The Mamdani method is selected due to the main reason that it considers of a lot of information and at the same time allows us to describe the skill in more intuitive, more human-like manner. In this method, there are three stages as explained below.

2.2.1 Fuzzification

In this step, the fuzzy sets inputs are defined. The inputs of the fuzzy are the object size and the expected angles of second, fourth and sixth bodies of the gripper to grasp the objects. Firstly, the three fuzzy set for object size are designed; small, medium and large. The ranges for input size is between 1 cm to 8 cm while the angles between 20° to 50°. On the other hand, for the outputs, the ranges for angle are between 20° to 50° and force between 2 N to 10 N. The force setting is design based on the report by Goodwin A. W. *et al*. [14]. This setting is illustrated in Table 2 and 3 for better understandings.

Table 2 Fuzzy set inputs and outputs: angle

Size	Angle	Theta
S	L	L
M	M	M
L	S	S

Table 3 Fuzzy set inputs and outputs: force

Size	Angle	Force
S	L	L
M	M	M
L	S	S

2.2.1 Rule Evaluations

By using the Mamdani technique, the positions of the three fingered gripper are identified. This step calculates the fuzziness of the system. Based on this processes, the object that has been grasped will be guaranteed from being dropped and the finger will be actuated based on the specified value. The fuzzy sets rules are mentioned in Table 4 below.

Table 4 Fuzzy rule

1. If (size is small) and (angle is large) then (theta is large) (force is small)
2. If (size is medium) and (angle is medium) then (theta is medium) (force is medium)
3. If (size is large) and (angle is small) then (theta is small) (force is large)

2.2.2 Defuzzification

This step determines the output of the system which are the gripping angle and torques of the body. The output will be based on the calculations of the previous two stages to obtain the expected outputs of orientation angles and torque.

3.0 RESULTS AND DISCUSSION

This section discussed about the findings based on FLC and feedback control applications. Figure 3 shows the initial position of the gripper before grasping any objects. Figure 4 shows the gripper which has grasped the object with suitable angles and torques. Remark that there are no sensors applied during simulations.

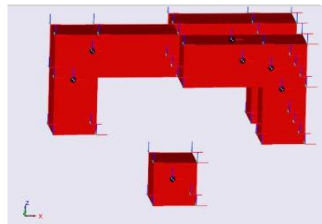


Figure 3 Initial position

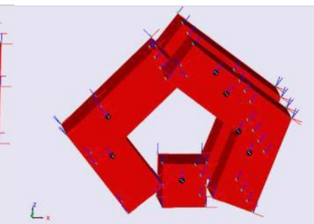


Figure 4 Final position

Table 5 presents the angle orientation between non-fuzzified and fuzzified gripper for the different gripper bodies to grasp the object. As can be observed from the table, the non-fuzzified system illustrated that angle orientation is smaller. This means that the three bodies are not moving appropriately to grasp the object. To overcome this, FLC offers a solution by controlling the bodies' angle to grasp accordingly to the object size and dimensions. Through the constructed rules, number of fuzzy sets and membership types, the grasping can almost be achieved within the same time which is 0.5s where the non-fuzzified system is not capable of doing to. To describe about the torques being applied by each body to the object, Table 6 is presented. This table demonstrates the advantages of having FLC in gripper system for the applied force based on FLC design. The data in Table 6, indicated that the applied torques for the non-fuzzified system is almost similar to the fuzzified system torques performance except Gaussian membership. The Gaussian membership has higher applied torques than the others. However, these three types of membership are still not capable of grasping the object firmly.

The investigation continues with an analysis of the system when it is added with a controlled feedback. This closed loop system is designed to be included to adjust the outputs as desired as shown in Figure 2. The feedback function is added after the FLC to reduce the processing time. By adding the feedback function, the system is able to grasp the object firmly especially for any FLC design that still cannot grasp the object on its own as expected. The analysis is tested for different number of rules which are 3 rules, 9 rules and 25 rules. Among these rules, the best rule is chosen which is applied in this research. 3 rules have produced its best result which can effectively grasp the object for different membership functions. Unfortunately it is found that the angle orientation for Gaussian membership design is less than angle orientation of other membership types within 0.5s. The technique requires more time for grasping purposes. Moreover, the torques for Gaussian membership is also smaller than the expected torques needed to grasp the object. Table 7 shows the angle orientation and torques for each membership functions. These values are only recorded for gripper bodies that grasp the object.

Table 8 shows the comparison of elapsed time for each membership functions applied in this system. Trapezoidal takes less time but, Gaussian takes too long elapsed time for feedback system. In industrial application, the choice shall give preference to the one that offers less elapsed time. For the non- feedback, Triangular offers less elapsed time than others while the Trapezoidal is high and slow for the system. Further details of performance about the non-fuzzified and fuzzified gripper system will be presented through Figures 5-10.

Table 5 Angle for fuzzy and non-fuzzified system

Angle	Non-fuzzy(⁰)	Fuzzy(⁰)		
Body		Gauss	Trap	Tri
2	6.632	42.24	53.12	53.12
4	-3.581	-31.78	-41.38	-41.38
6	-3.581	-31.78	-41.38	-41.38

Table 6 Torques for fuzzy and non-fuzzified system

Torques'	Non-fuzzy(Nm)	Fuzzy(Nm)		
Body		Gauss	Trap	Tri
2	25	38.96	30	30
4	25	38.96	30	30
6	25	38.96	30	30

Table 7 Angle and torques for feedback (Fk) system

Fk	Angle (⁰)			Torques (Nm)		
Body	Gauss	Trap	Tri	Gauss	Trap	Tri
2	5.061	6.908	6.908	-122.2	-173.9	-173.9
4	-11.7	-16.43	-16.43	-122.2	-173.9	-173.9
6	-11.7	-16.43	-16.43	-122.2	-173.9	-173.9

Table 8 Comparison of elapsed time

Time		Elapsed time (s)
Membership functions	Feedback	Non-feedback
Gauss	0.001176	0.001223
Tri	0.001133	0.001209
Trap	0.001045	0.001318

Figure 5 shows the angle orientation for thumb body between fuzzified and non-fuzzified gripper system. The angle orientation for the non-fuzzified system is small because of it is an open-loop system and it is difficult to check whether the gripper has grasp the object or not.

In fuzzified system with three rules design, the angle of Gaussian membership type is smaller than the others two membership types. Besides, it shows slower grasping time. Interestingly, if the rules are increased to nine rules, all the membership types can grasp fairly the object. Nevertheless, as time consumption is considered, the design of three rules with feedback system has better advantages compared to the nine rules. This is simply due to more processing time needed to include the effect of having nine rules in the system. Refer to Table 9 for the time consumption of these two design cases. Same results are observed for different gripper bodies as illustrated separately in Figure 7, and Figure 9. In those figures, the angle orientations are negative because of the axis for middle and index is opposite to the thumb body.

Besides, the orientation angles are not able to grasp the objects as required. Looking into the grasping torque performance, Figure 6, 8 and 10 compares the performance between fuzzified and non-fuzzified system for FLC with three rules design. As illustrated, the applied torques is bigger than the non-fuzzified system. Even if this is the case, the gripper still cannot grasp the object. However, by applying the feedback system, the orientation angle and applied torque describes that the gripper can firmly grasp the object as depicted in Figure 11-12. Note that the torques is calculated based on the applied force in y axis. In addition, the angle orientation in Figure 11 is smaller than the non-feedback system. This Characteristic demonstrates that the upper body moves faster than the second body and can be understood if Figures 2-3 are referred. These properties are similar to the human grasping movements. To summarize, both of the paper objectives have been achieved which are to evaluate the performance of fuzzified system and the effect of having a feedback system in a gripper system.

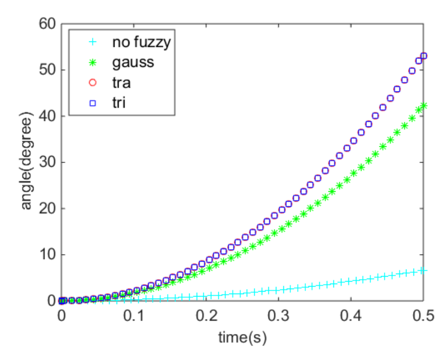


Figure 5 Angle in body 2(thumb) for non-fuzzy and fuzzy

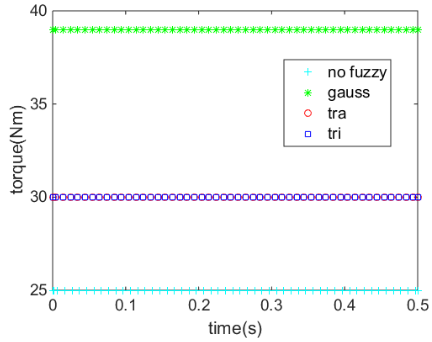


Figure 6 Torques in body 2(thumb) for non fuzzy and fuzzy

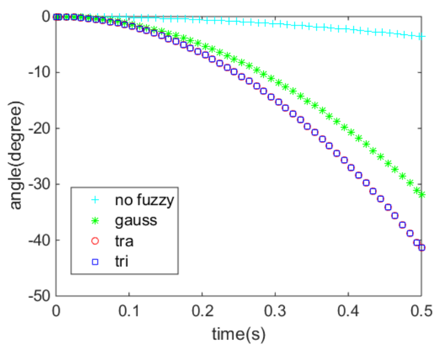


Figure 7 Angle in body 4(middle) for non-fuzzy and fuzzy

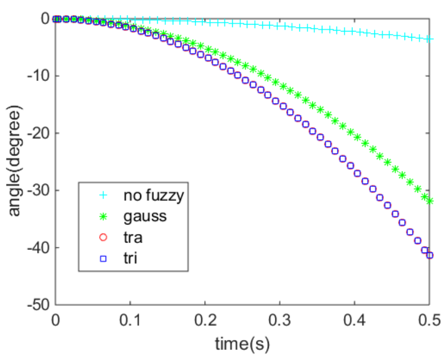


Figure 8 Torques in body 4(middle) for non-fuzzy and fuzzy

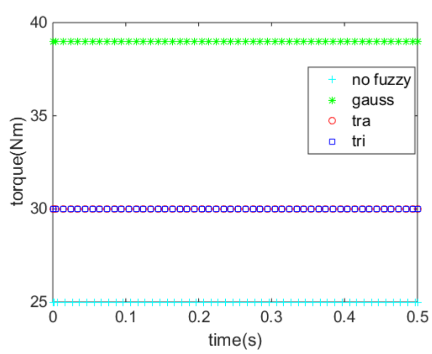


Figure 9 Angle in body 6(index) for non-fuzzy and fuzzy

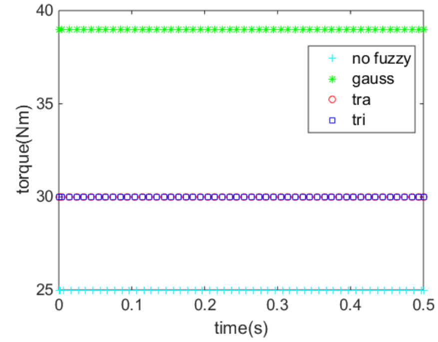


Figure 10 Torques in body 6(index) for non-fuzzy and fuzzy

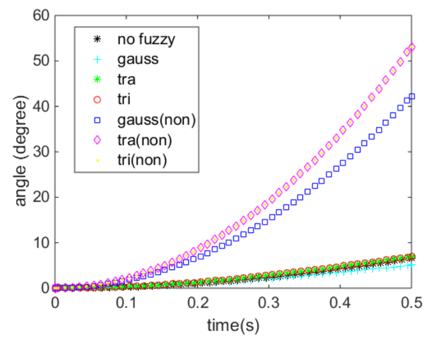


Figure 11 Angle in body 2 for feedback and non-feedback

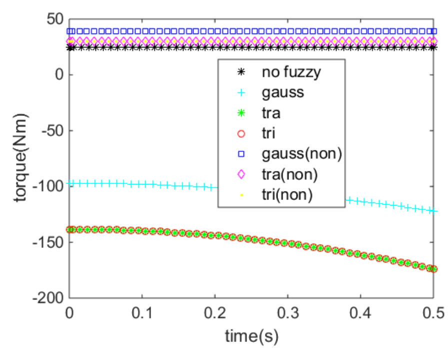


Figure 12 Torques in body 2 for feedback and non-feedback

Table 9 Comparison of time consumption for different design cases

Type of membership	Type of feedback	Type of feedback
Gaussian	0.001176s	0.000985s
Triangular	0.001133s	0.001257s
Trapezoid	0.001045s	0.001209s

4.0 CONCLUSION

This paper has presented a study about the dynamic performance of a gripper system which analyses the consequences of having a FLC and a feedback system. The results suggest that the FLC and a feedback system offer better performance compared to a conventional system. In conclusion the study indicates that FLC and a feedback system with a minimum three rules can provide faster and better grasping compared to a system that used nine rules of FLC only.

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