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SYSTEM IDENTIFICATION AND FUZZY LOGIC CONTROLLER DESIGN FOR PROSTHETIC HAND SYSTEM

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Abstract

Hand is an important parts of human physical bodies that have high complex structure with highest precision, flexibility and accurate movement involve a lot of numbers nerve connected. Amputees are people who have difficulties when dealing with their routine or daily life activities because of physical problem. This project to focus on the designing the prosthetic hand consist of the intelligent controller based on the multiple rule that having capabilities to operate on fuzzy logic control algorithms for amputees. This project utilized fuzzy logic controller to control the positioning of prosthetic hand as feedback input to provide the membership rule in fuzzy logic control algorithm. The results show that the designed controller has good capabilities to accurately control the prosthetic hand system.

Keywords: Prosthetic hand, Amputee, Fuzzy Logic, System identification.

1. Introduction

Based on history, the development of the prosthetic hand was invented by using a combination concept between electrical and mechanical forces in control system of an electrical prosthesis advanced introduces since in 1965 [1]. The most prosthetic hand technology is precisely not having much different in terms of quality control related to human hand. The efficiency of operational prosthetic

Nomenclatures

x	Voltage, V
y	Displacement, mm

Abbreviations

ABS	Acrylonitrile Butadiene Styrene
DoF	Degree of Freedom

hand can be increase using a positioning as a feedback to define and improving the system by reducing the disturbance or error [2].

The prosthetic hand will be designed and fabricate according the human hand by replacing a linear actuator, electrical instrument, processing control system and few instruments to replicate the flexibility in finger movement. This research focus only one Degree of Freedom (DoF) design where is fully functional by using dc motor to control the linearity movement finger. The best design in development cosmetic prosthetic hand that will increase the performance and efficiency must be follows the criteria such as a low energy consumption, simplicity control system, less friction, reduction of sizing actuator and simple grasping design approach by reducing the active degree of freedom (DoF) [3].

In this paper, the design considered briefly about develops a mathematical modelling of the prosthetic hand using system identification techniques. After that, the control system is designed using artificial intelligence technique which is fuzzy logic control algorithm. Lastly, the effectiveness of controller is evaluated via simulation.

2. Related Research Works

Intelligence controller is capable to perform robust control prosthetic hand system by expanding the range of uncertainty for which performance specification can be achieved or tuning the controller based on method that being used. The main issues in designing a control system is robustness for the underlying controller design implemented in system. There are various types of design system controller methods. Each method are having their structure and technique where provide a different benefits and flexibility such as PID controller, Artificial Neural Network controller, Neuro-fuzzy controller, Bayesian controller and Fuzzy logic [1-3].

Maeda and Chou has introduced one of method which self-tuning algorithm in fuzzy logic control by adjusting the scaling factors which parameters of the fuzzy logic control and improving the control rule[4,5]. The design of self-tuning fuzzy controller can improve the control rule by evaluating the control response at real time and control the result after operation. The design of self-tuning fuzzy controller purpose to uses the control error and the several count difference of the control error as input variable. The self-tuning rule are consist of three heuristic rule sets which are repeated use such as learning rule (scale adjustment rule), the real-time learning rule (modification rule) and evaluation rule (control response) [4].

There are also an idea to develop the better prostheses hand with technology and efficient system modelling. There are having a studies to determine and compare three different control algorithm for a muscle-like actuated arm developed by using fuzzy controller, fuzzy-MA controller and Proportional-Integral-Derivative (PID) controller where it's suitable to become a reference to the prostheses hand which controller are more robust. The studies show the fuzzy logic control implies the moment arm scaling is an effective tool for improving motion tracking accuracy in mechanical arm where it's determines relative error and correlation. The PID controller also can be used to replace fuzzy based controller but it's more to tuning and determine the suitable gain [6].

Some paper introduced different kind of step where this concept of auto tuning have been appeared since 1980. This paper presented a new concept approach by selecting an appropriate sampling time for standard process to implement a normalised fuzzy logic controller for the standard process. The unknown processes will applied the biased relay feedback test and the first-order process towards dead time model must be fit with the output response. The fuzzy logic control will functional to stabilize the fuzzy logic control based on estimated system gain, time constant and time delay. Fuzzy logic is included to compensate for effect of delay introduce in the feedback loop such that the control loop result become more stable [5].

3. Method

This section explains the development of a prosthetic hand control system in order to achieve the research's objective. The first section covers the construction design and fabrication on prosthetic hand with details about materials that being used. The second section explain the data collection process of several test input and output data for system identification. This section also covers the mathematical modelling to provide the initial condition of displacement motor. The third section covers about development of the controller. The intelligence control method that being used in this project is a fuzzy logic controller. Figure 1 shows the flowchart of the research work.

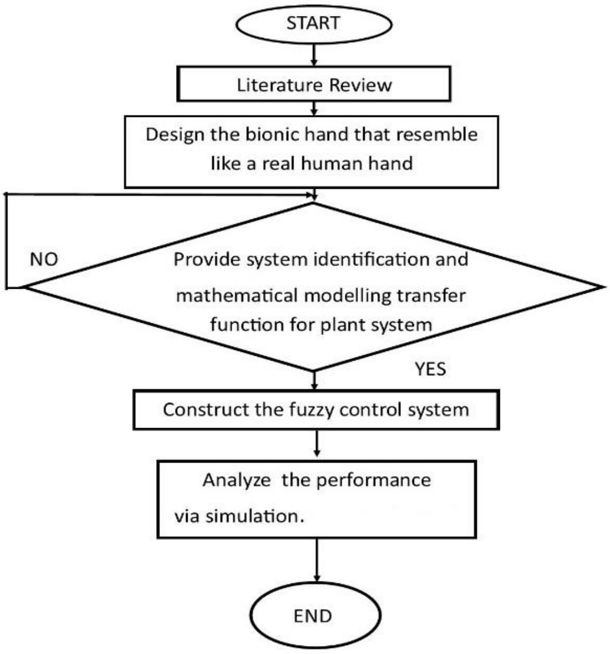

Fig. 1. Flowchart of the works.

3.1. Fabrication of the prosthetic hand

The prosthetic hand consist of one Degree of Freedom (DoF) required to attract only one of jointer linkages in linear movement for each fingers. The hardware is designed using Solidwork before it is fabricated using 3D printer because it's is low cost construction and easier resource to develop. 3D printed plastic parts work like bones and a rubber coating acts as the skin to presence like a human hand [7]. The material that is used to fabricate the prosthetic hand is Acrylonitrile Butadiene Styrene (ABS). Figure 2 shows the overall combination part for normal condition while Fig. 3 shows the overall combination part for grasp condition.

Fig. 2. The overall combination part for normal condition.

Fig. 3. The overall combination part for grasp condition.

3.2. System Identification

The next procedure is calibration of the linear dc motor by mapping the voltage feedback, displacement and angle of finger. The voltage feedback is generated by using analog position feedback signal related to the potentiometer as a reference.

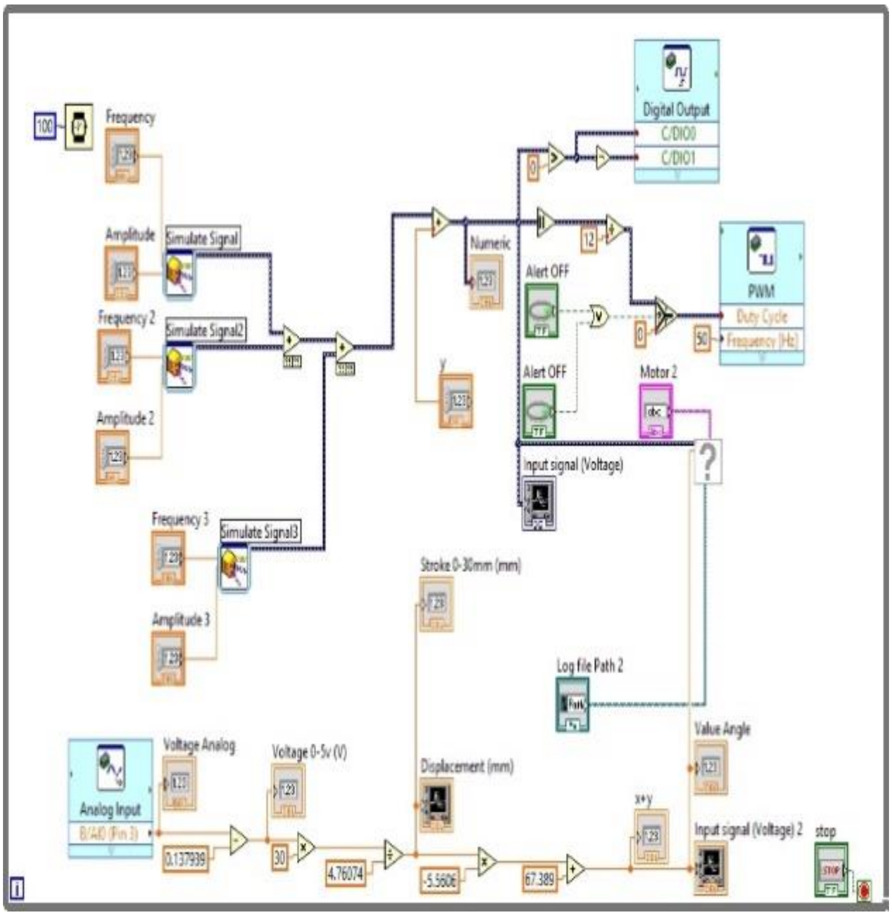

Fig. 4. Data collection block diagram.

Based on Fig. 4, the input data is generated by feeding several random input signal generate directly into the digital output where the driver motor is connected to give the forward and reverse motor [8]. The block diagram show PWM is applied into the system to supply the pulse signal into the linear dc motor by setting the constant frequency. Alert OFF is provided to avoid from damaging on linear dc motor as safety requirement to controlling the stroke motor. The voltage analog is subtracted by 0.137939 to set the zero initial condition displacement motor because error of displacement mechanism linear dc motor. Then the output of the initial condition is multiplied with 30mm means that stroke of motor before divide 4.76074 as input reference voltage.

Table 1. Test model Specifications and test conditions.

Voltage feedback (V)]	Displacement (mm)
1.8457	11.6308
1.4600	9.20001
1.1951	7.53077
0.8325	5.24616
0.4944	3.11539
0.0037	0.0230797

Based on Table 1, the data show the relationship between parameters that need to be considered by applying the equation of gradient. The calibration between voltage and displacement can be analyse by Eq. (1).

$$y = \frac{30}{4.76074} x + 0.137939 \tag{1}$$

where x is voltage (V) and y is the displacement (mm).

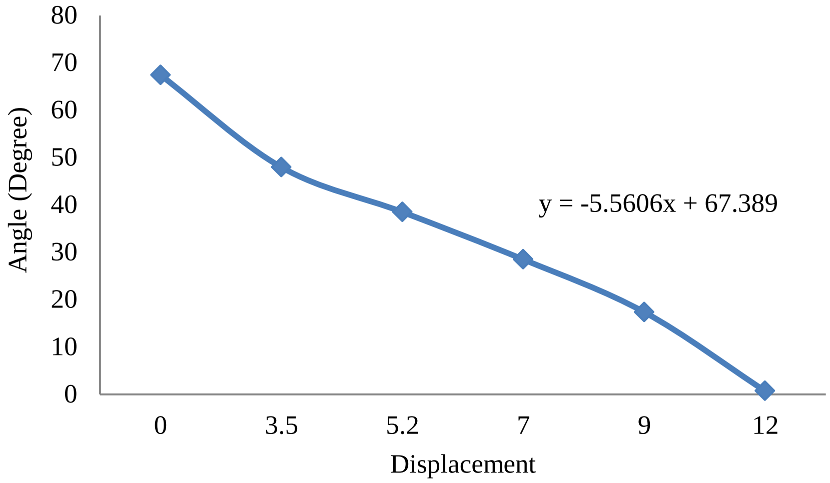

Fig. 5. The relationship between the angle and displacement.

Based on the Fig. 5, the angle of position finger where the left middle phalanx as reference point show that the maximum angle is 67.389˚ with gradient -5.5606. When the angle of left middle phalanx reach to the maximum point of angle, the fingers are totally in 90˚ degree angle. Now, the system has already been converted the voltage feedback into the angle positioning before we can proceed to the system identification. System identification is a process to convert the overall plant process into the mathematical modelling transfer function to simulate and evaluate the response of signal depending on the input given. The system identification process is done in MATLAB system identification tool.

3.3. Fuzzy logic controller design

The fuzzy logic controller will consider the error and derivative error as an input variable linguistic into fuzzy controller [6]. Table 2 shows the membership rule.

Table 2. Rule of fuzzy control system.

Error \ Derivative error	N	Z	P
N	N	N	Z
Z	N	Z	P
P	Z	P	P

where N is negative, Z is zero and P is positive.

The rule was assign using the fuzzy toolbox in MATLAB. Firstly, the error input linguistic varible membership function is designed. The system cover the range between -0.5 until 0.5. These design type is triangular where it will taken the crisp value of error into the fuzzification proses. The range membership function shows the three range need to consider.

Mf1(N) : [-0.9 -0.5 -0.1997]
Mf2(Z) : [-0.306 0 0.3056]
Mf3(P) : [0.1997 0.497 0.897]

Next, the design cover on change error input linguistic variable membership function. The system cover the range between -1 until 1. The design type is triangular where it will taken the crisp value of change error into the fuzzification proses. The range membership function shows the three range need to consider.

Mf1(N) : [-2 -1 0]
Mf2(Z) : [-0.315 0 0.2937]
Mf3(P) : [-0.00529 0.995 1.99]

Lastly, the design cover on output linguistic variable membership function by selecting implication minimum method on between two input varibles. The system cover the range between 0 until 1. These design type is triangular where it will complete the calculation to convert the output fuzzy value into the crisp value by using a Center of Area method. The range membership function shows the three range need to consider.

Mf1(N) : [-0.5 0 0.504]
Mf2(Z) : [0.00132 0.5 1.004]
Mf3(P) : [0.5013 1 1.5]

The left middle phalanx as reference point show that the maximum angle is 67.389˚ with gradient -5.5606. When the angle of left middle phalanx reach to the maximum point of angle, the fingers are totally in 90˚ degree angle. Next, the system has already convert the voltage feedback into the angle positioning before we can proceed to the system identification. System identification is a process to convert the overall plant process into the mathematical modelling transfer function to simulate and evaluate the response of signal depending on the input given. The system identification process is done in MATLAB system identification tool.

4. Results and Discussion

4.1. System identification

Figure 6 describe the relationship between voltage and position of dc motor's angle. The graph shows the difference between the input voltages with desired angle. The second result in Fig. 6 shows the voltage input on the transfer function. Meanwhile, the graph at the top of the figure shows the position of angle on output. The positive input voltage provides the increasing of position angle on motor. The output result positioning show the signal was completely are randomly in angle range 0˚ until 67˚ a maximum angle. The data is collected at the specific time when the motor positioning are maintain at certain angle and constant movement.

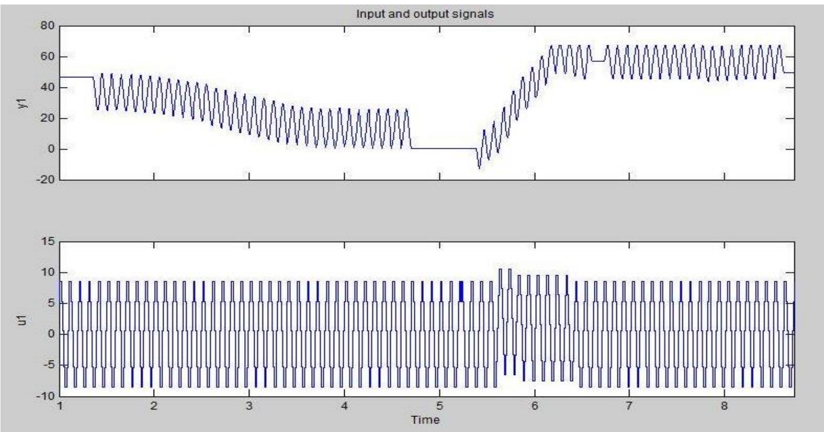

Fig. 6. Input and output data collected.

Figure 7 shows the collected data that is used to simulate in system identification toolbox. The fitness of the model should be greater than 80% because the data is reasonable and can be used for simulation purpose. The positioning output and input data is being measured at 7.15 seconds to 7.35 seconds. The graph show the angle is taken at 67.389˚ degree when the finger is in grasp condition.

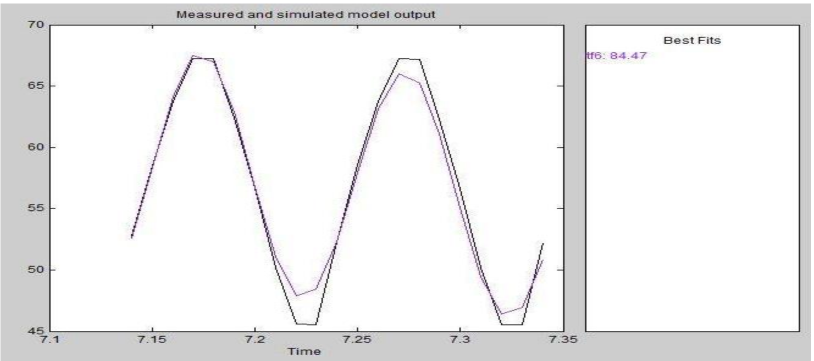

Fig. 7. Measurement and simulate model output.

The transfer function is determined to simulate the system. The mathematical modelling obtained is performed in discrete transfer function as in Eq. (2) for easiness during analysis and validation later. The controller is analyses analogue input value in terms of logical variables that taken from continuous value before analyse to digital logic which operate on discrete value.

$$Gz_1 = \frac{0.2223z^2}{z^3 - 2.053z^2 + 1.53z - 0.4754} \tag{2}$$

The parameterization that had been used on discrete transfer function has three numbers of pole and one numbers of zeros. The sample time required where the signal perform is 0.1 second and the number of free coefficient is four.

4.2. Stability

Figure 8 shows that the location pool and zero in the root locus where the pole at the positive side and inside the unit circle will consider as a stable condition. The stability continuous transfer function is totally different to analyses compared with discrete transfer function. The continuous transfer function stability can be refer on location of pole located on the left side *s*-plane. Meanwhile the discrete transfer function can be describe stability on location of pole inside the unit circle on *z*-plane. The response will oscillated when the pole are total located on the unit circle.

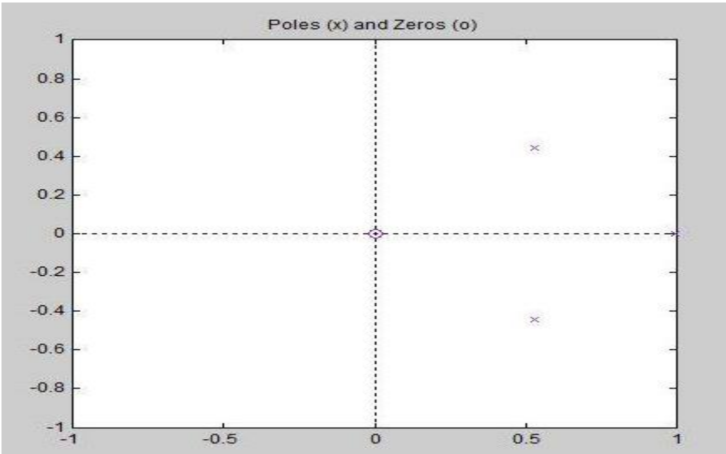

Fig. 8. Pool and zero location.

4.3. Open Loop Transfer Function

Figure 9 shows an open loop output response when applying 67˚ degree as a step input in plant system. The graph shows the response is uncontrollable because the system does not have a feedback. The maximum output reach until 9000˚ degree. So the system is totally out of the range to control the angle of the finger. Table 3 shows the step info response on the open loop system. The overshoot of open loop system is totally zero but the system take a long time settling the signal with desired level.

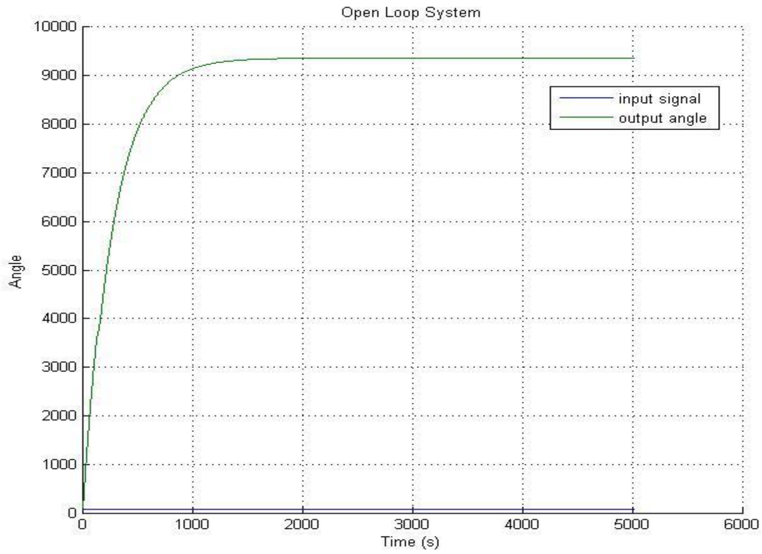

Fig 9. Step response open loop.

Table 3. Step info open loop system.

Response	**Unit**	**Value**
Rise Time	second	**576.2357**
Settling Time (second)	second	1.0272 e^3
Settling Min (second)	second	8.3811 e^3
Settling Max (second)	second	9.3088 e^3
Overshoot (%)	%	0
Undershoot (%)	%	0
Peak (degree)	degree	9.3088 e^3
Peak Time (second)	second	5000

4.4. Close Loop Without Controller

Figure 10 indicates the close loop output response with the feedback positioning angle without the controller. During the initial condition, the signal rise until it reaches at the certain point peak signal. Initially, the system produces high overshoot in order to emulate the desired value [9]. The signal oscillates for several seconds before it reach close to the reference signal.

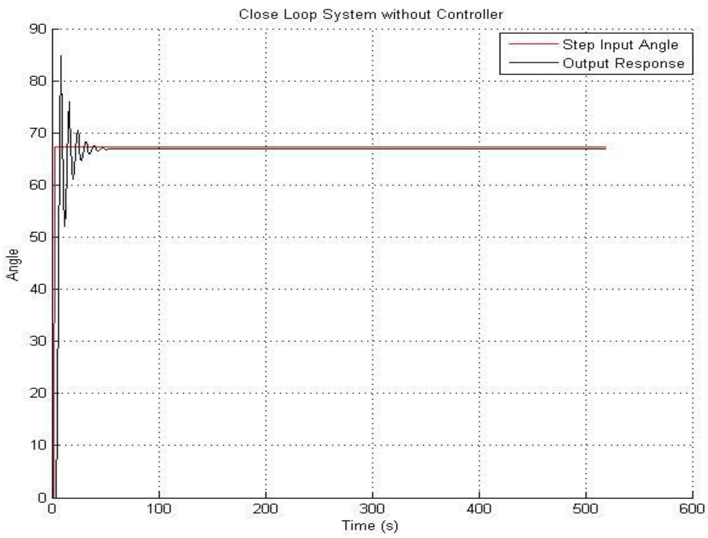

Fig. 10. Close loop system without controller.

Table 4. Step Response Close loop transfer function without controller.

Response	Unit	Value
Rise Time	second	4.2807
Settling Time (second)	second	9.9721
Settling Min (second)	second	49
Settling Max (second)	second	49
Overshoot (%)	%	136.7347
Undershoot (%)	%	0
Peak (degree)	degree	116
Peak Time (second)	second	8

Based on Table 4, the close loop transfer function performance can be determine in more specific location by using a step info command into the MATLAB. The response shows the rise time, settling time, overshoot and peak value. The overshoot for this system is very high and achieved until 136.7347. Usually, the good performance is provided with less but not equal to zero overshoot value. The less settling time and error need to be consider on plant system.

5. Conclusions

In conclusion, the fuzzy logic controller produce an acceptable performance when integrate with the prosthetic hand's system. The system identification process is performed to model the prosthetic hand system mathematically for simulation purpose. The mathematical modelling can be prove and validate by determine the location of pole inside the unit circle. The main objective is to control the angle of position finger using a linear actuator. The result show the fuzzy control system has improved the plant response. Therefore, it can be conclude that fuzzy logic controller is capable improve the performance of the system.

The prosthetic hand can be further improved by using a sensor as a feedback to the one of input linguistic variables on the fuzzy logic controller. The sensor measured the relative error and actual error to operate the linear dc motor. Thus the sensor can determine the actual value force need to grasp the object. The crisp value force can be defined as a one of the input on fuzzy logic system. The design should be better because the fuzzy system define the relationship between three input variables and rule.

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