CLAWAR 2019: 22nd International Conference on
Climbing and Walking Robots and the Support
Technologies for Mobile Machines,
Kuala Lumpur, Malaysia, 26-28 August 2019.
https://doi.org/10.13180/clawar.2019.26-28.08.34

# INTERVAL TYPE-2 FUZZY LOGIC WITH PARTICLE SWARM OPTIMIZATION FOR DC MOTOR POSITION CONTROL

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The main principle of this project is to control the position of the train door system by using Direct Current (DC) motor which has nonlinear behaviour. A Particle Swarm Optimization (PSO) optimized Interval Type 2 Fuzzy Logic Controller (IT2FLC-PSO) is proposed to control the position of DC motor with application to train door position control. The mechanism of the train door system is developed by using SimWise 4D and integrated with Matlab Simulink for control purpose. Then, the system identification tool is used to obtain the mathematical model of the system based on the input and output value in Simwise 4D motions. A comparative study is carried out using Type 1 Fuzzy Logic Controller (T1FLC) and a IT2FLC-PSO. Lastly, simulation results are presented in Matlab/Simulink and the performance of the proposed algorithms in controlling the position of the train doors is evaluated with various weights and sizes of the door.

Keywords: DC Motor Control, Position Control, IT2FLC based PSO.

## 1. Introduction

The performance motor drive is significant in industrial as well as other electromechanical applications such as steel rolling mills, electric trains and robotics. DC motor has simple structure, high reliabilities and flexibilities and the price of DC motor is favourable for most horsepower ratings [1]. Furthermore, DC engine generally applies in modern applications, robot controllers and home machines where speed and position control of engine are required [2]. DC drives are less intricate with a solitary power transformation from AC to DC. Moreover, several research and algorithms or methods have evolved in controlling the position of DC motor. Since DC drive is widely use in various applications, in order to contribute the desired operations and perform desired output, DC motor should be precisely controlled.

Various optimization algorithms have been employed to hold the position of the motor. In position controller of DC motor, non-linearity of DC motor is the major problems while using a conventional control algorithm (PI, PD, and PID). Motor saturation, motor friction and quantization noise in the measurement sensors are contribute to the exhibition of behaviour of non-linear in DC motor [3]. The parameter tuning in conventional methods is difficult to solve the problem generate by non-linear characteristics of a DC motor and even could degrade the performance of conventional controllers. The nonlinear features of DC motor such as friction and saturation able to make the performance of conventional controllers downgrade.

In the process of controlling the DC motor, engineers were faced the complex nonlinear process of the DC motor. A mathematical model is required in controlling the DC motor and the task to obtain a mathematical expression from the nonlinear DC motor is complex. Hence, the simplest solution is using human factor. An experienced machine operator with the knowledge of the system is called human factor. It has the capability of imprecise observations and factor that impossible to apply in the intelligent controllers. The knowledge of FLC system is accumulated from an operator and mathematical tools. The mathematical tool can change the sentence words of the operator into numbers interpreted by machines. From the research, FLC has been a productive research area with numerous mechanical applications. FLC is introduced by L.A Zadeh in 1973 and implement (Mamdani 1974) in controlling the system that have a complex structural and difficult to model such as DC motor [4-19]. It recently replaced conventional control system among different type of engineering areas. However, T1FLC might not be able to fully handle the high levels of uncertainties associated with control applications. Interval Type 2 system is capable to perform in various complex and uncertain non-linear DC motor position control system to produce better performance [20-21]. The membership function of IT2FLC able to incorporate the linguistic term of input and output variable and handle the uncertainties effectively without the detail knowledge and information of the DC motor model. The extended concept and foundation of Type 1 Fuzzy Logic System is called Type-2 Fuzzy Logic System. By employing the PSO to Interval Type 2 Fuzzy Logic Control (IT2FLC) system, optimization of movement of train door can be observed. The comparison of performance between IT2FLC-PSO and T1FLC system is recorded in analysis part.

## 2 System Model and Parameters

Train door model is designed using SimWise 4D to allow the functional performance of mechanical parts and assemblies to be simulated and validated. It combines 3D multi body dynamic motion simulation with 3D finite element analysis. It represents the mechanical system which allows users to simulate and control the whole system and integrate the system with Matlab Simulink.

An existing file of the single train door which is integrated with DC motor is provided in SimWise 4D. The performance of DC motor is observed. The movement action of the train door file is moving from right to left. The train door is named as Door 2. In order to develop a complete train door system, the Door 2 is duplicated to form two train doors and the duplication of Door 2 is named as Door 1. The initial position of Door 1 changes to the left side to make the door move in opposite way which is from left to right. The initial and final position of both train doors is measured from the properties window of the door. Table 1 states the initial and final position of the train door. When Door 1 is located at -2.07 m and Door 2 is at 0 m the train door system is closed (Figure 1), and is opened when the Door 1 is at -1.32 m while Door 2 at -0.75 m (Figure 2).

**Table 1.** Initial And Final Position Of Door 1 And Door 2.

| Position | Door 1 : Move from Right to Left | Door 2 : Move from Left to Right |
|---|---|---|
| Initial /m | -1.325 | -0.750 |
| Final /m | -2.067 | 0 |

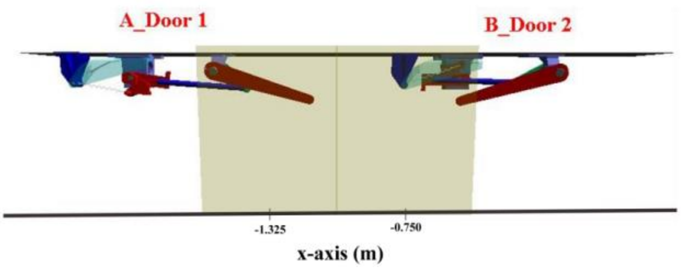


Figure 1. The train door is closed.

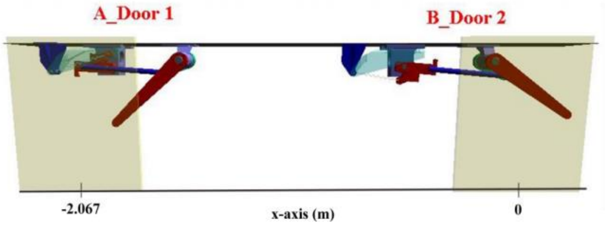


Figure 2. The train door is opened

Besides, the unit of distance and rotational velocity is set to meter and degree/second. Input slider is added to control the rotational velocity of the revolute motor that attach on the engine shaft of the train door engine arm. Furthermore, a position meter measured at x-axis is added to evaluate the position of the train door as depicted in Figure 3.4. Furthermore, friction is added to all the revolute joints and spherical joints accept the joint between damper bracket and damper pin with the coefficient of friction is 0.2 and the effective radius is 0.001.

The maximum of train door weight is 120 kg as referred to [22]. The maximum weight of door can be controlled is determined. The minimum door size according to [23] is 1.5 m (W) x 1.9 m (H). The body size of train door with 0.5778 m (W) x 0.7095 m (H) is based on the ratio of minimum width to height. Another door size of 0.5778 m (W) x 1.9 m (H) and square size of the door 0.5778 m (W) x 0.5778 m (H) are tested. The train door is initially closed. The movement of train door is designed to opened and closed within 16 seconds. The door is opened at 4th seconds and closed at 10th seconds.

## 3. Intelligent Control Systems

### 3.1. *Type-1 Fuzzy Logic Control (T1FLC)*

Figure 3 is the block diagram of type 1 FLC. FLC consist of three basic steps which are fuzzification, fuzzy inference process and defuzzification. In fuzzification, the crisp input data are converted into linguistic fuzzy data or membership functions in fuzzifier block. Then, the input fuzzy data are combined with control rules to derive the fuzzy output data in fuzzy inference process of inference engine block [24]  In defuzzifier block, the fuzzy output data is then transformed to crisp data which is the input data of the system in the process of defuzzification.

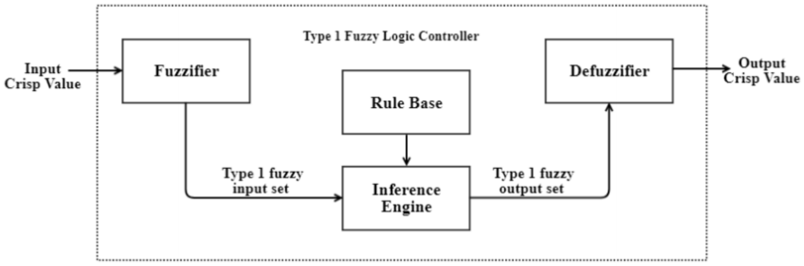
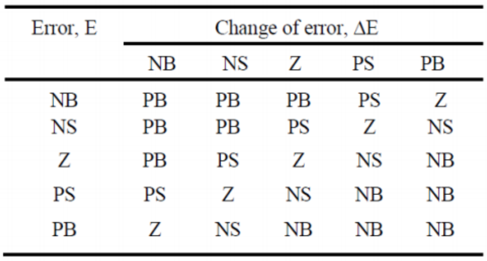


Figure 3.Block Diagram of Type 1 FLS [13].

The designed type 1 FLC consists of two inputs and one output. The fuzzy inputs are error and change of error and the fuzzy output is the control signal. Both variables have five Membership Functions (MFs) such as Negative Big (NB), Negative Small (NS), Zero (Z), Positive Big (PB) and Positive Small (PS). Table 4 is the stability rule base which is referred from [25]. Type 1 FLC is modeled by using Matlab fuzzy toolbox.

**Table 2.** Standard stability rule base.



| Error, E | Change of error, ΔE | | | | |
|---|---|---|---|---|---|
| | NB | NS | Z | PS | PB |
| NB | PB | PB | PB | PS | Z |
| NS | PB | PB | PS | Z | NS |
| Z | PB | PS | Z | NS | NB |
| PS | PS | Z | NS | NB | NB |
| PB | Z | NS | NB | NB | NB |

### 3.2. *Interval Type-2 Fuzzy Logic Controller (IT2FLC)*

Interval Type 2 Fuzzy Logic System (IT2FLS) has the same concept as T1FLC except in the defuzzification step. At the defuzzification, reduction is required to reduce type 2 fuzzy set into type 1 fuzzy set. The output is presented in singleton. The block diagram of IT2FLS is shown in Figure 4. IT2FLS is programmed as Matlab function file which is based on simplifying the representation of the IT2FLS inference mechanism. Nie–Tan reduction method is applied in defuzzification.

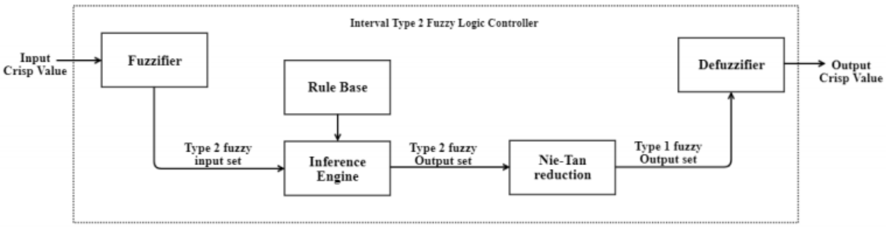


Figure 4. IT2FLS block diagram.

IT2FLS is presented in closed-form mathematical formed [26-30]. The fuzzy rule used is same as T1FLC. The MFs of each variables distribute uniformly within -1 to 1. The center of upper and lower MFs is same and center of each MFs are stated in Table 3.

**Table 3.** The Centre of Membership Function.

| MF | NB | NS | Z | PS | PB |
|---|---|---|---|---|---|
| Centre | -1 | -0.5 | 0 | 0.5 | 1 |

### 3.3. *Type-2 FLC Nie-Tan Reduction Method*

Nie-Tan method output a representative type-1 fuzzy set by obtaining the average of the upper and lower membership functions of the FOU of the IT2 FS output. The crisp output is calculated as the center-of-gravity of reduced Type 1 fuzzy. Approximate Gaussian forms for both the UMF and LMF to simplify the representation when the utilized IT2 membership functions have uncertain means. Besides, max and min operators are avoided for uncertain mean. Hence, UMFs and LMFs is redefined. The UMF and LMF are approximated with Gaussian equivalents using curve fitting techniques.

## 4. Particle Swarm Optimization (PSO)

PSO use a number of particles that constitute a swarm moving around in the search space looking for the best solution. The next position of particle is guided by Personal experience (Pbest) and overall experience (Gbest) and the present movement of the particle. Parameter c1 and c2 are the acceleration factor use in accelerate the particle by depending on the experience. Parameter c1 and c2 can be any value as long as the summation of c1 and c2 is 4. wmin and wmax is the inertial weight which multiplied with the present movement of the particle. N is the number of particle and 'maxite' is the number of iteration. The objective function used in this project is to minimize sum square error.

## 5. Simulation Results

Six gains are used in the controller system. Each door consists of 3 gains which 2 gains located at the input of controller and 1 gain is at the output of the controller. K1, K2 and K3 are for Door 1. K4, K5 and K6 are for Door 2. The gain values of T1FLC are obtained by intuitive method while the gain value of IT2FLC is obtained by PSO. The gain values are tabulated in Table 4. The performance of both controllers is evaluated with SWplant system. The performance of both controller is presented within a graph for each door. The controllers are tested with different dimension of train door and different weight of train door. T1FLC and IT2FLC-PSO are tested under different value of weight and dimension. In term of weight, the controllers can afford up to 100 Kg for each side of door. The simulation results for each weight are same and the result is depicted in Figure 5 and Figure 6. These verified that the IT2FLC-PSO is performed better than T1FLC.

**Table 4.** Gain parameters of T1FLC and IT2FLC-PSO.

| Parameters | T1FLC | IT2FLC-PSO |
|---|---|---|
| K1 | 2 | 11.5812 |
| K2 | 0.001 | 0.1289 |
| K3 | 700 | 791.3792 |
| K4 | 2 | 12.952 |
| K5 | 0.001 | 0.1131 |
| K6 | 700 | 722.4411 |

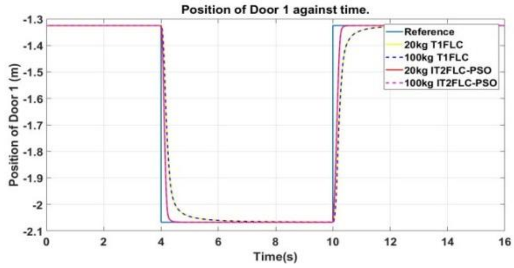


Figure 5. The performance of Door 1 with different door weight.

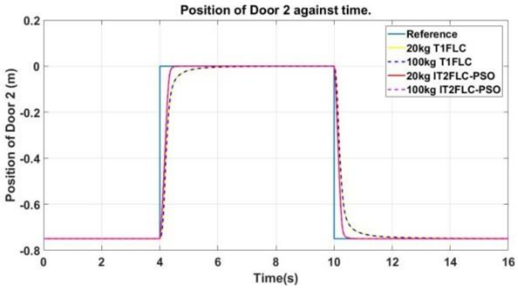


Figure 6. The performance of Door 2 with different door weight.

T1FLC and IT2FLC-PSO are also tested under 3 different sizes of train door. The simulation for square size 0.5778 m (W) x 0.5778 m (H), the rectangular size of 0.5778 m (W) x 0.7095 m (H) and 0.5778 m (W) x 1.9 m (H) are same as shown in Figure 7 and Figure 8.

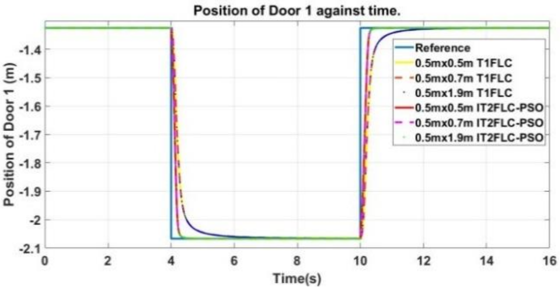


Figure 7. The performance of Door 1 with different door size.

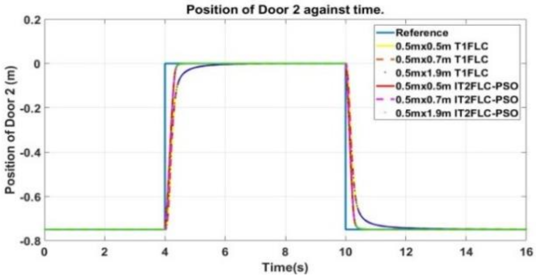


Figure 8. The performance of Door 2 with different door size.

Table 5 and Table 6 have stated the rise and settling time for both doors in open and close movement.

**Table 5.** System performance of door 1

| Door 1 | Open | | Close | |
|---|---|---|---|---|
| | T1FLC | IT2FLC-PSO | T1FLC | IT2FLC-PSO |
| Rise Time (s) | 4.503 | 4.221 | 10.611 | 10.279 |
| Settling Time (s) | 0.343 | 0.157 | 0.395 | 0.195 |

**Table 6.** System performance of door 2

| Door 2 | Open | | Close | |
|---|---|---|---|---|
| | T1FLC | IT2FLC-PSO | T1FLC | IT2FLC-PSO |
| Rise Time (s) | 4.74 | 4.38 | 10.77 | 10.355 |
| Settling Time (s) | 0.379 | 0.251 | 0.379 | 0.217 |

From the simulation results of both train doors, the most difference 0.415 second is the differences of rise time of Door 2 at close movement. The least difference is the difference in settling time of Door 2 at an opening movement which is 0.128. In overall, IT2FLC-PSO has less rise-time and settling-time compared to T1FLC in both opening and closing movement. No overshoot for both controllers.

## 6. Conclusion

The performance of the IT2FLC-PSO has been compared with Type-1 FLC in terms of several performance measures such as rise time, peak overshoot and settling time. The IT2FLC-PSO has shown better performance over the type 1 FLC under varies weight of door up to 100 Kg and 3 different door sizes. PSO approach provides the effective gain value through minimizing the error between desired door position and actual door position. The fuzzy input output gain parameters and Interval Type-2 MFs provided by PSO able to give better results in term of controlling the position of DC motor. The simulation results show the potential applicability of the IT2FLC-PSO approach.

## Acknowledgments

The work presented in this paper is supported by Research grant (RDU170502) from Faculty of Electrical and Electronics Engineering, Universiti Malaysia Pahang and Ministry of Energy, Science, Technology, Environment and Climate Change, MESTECC.

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