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Comparative Analysis of Fuzzy Logic based Conventional PID Controller for Second Order System with Dead Time

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ABSTRACT

This paper deals with the design of a fuzzy PID Controller (FPIDC) with dynamic gain through a fuzzy scheme. The gain factor of Proportional, Integral and Derivative is varied according to process of the proposed dead time. FPIDC is modified which depends on the normalized change of error of the controlled variable (ec) and its number of fuzzy partitions. The proposed scheme is tested for a wide variety of second-order systems with different dead-time (L) under both set-point change and load disturbance. Detailed performance comparison with a well-known fuzzy PD controller and fuzzy PID controller reported in the leading literature is provided with respect to a number of performance indices. The proposed controller is designed using a very simple control rule–base having seven rules and triangular membership functions. Simulation results justify the effectiveness of the proposed scheme. The simulation results under MATLAB environment has predicted better performance with fuzzy PID controller with different values of Dead Time under all operating conditions of the drive. In results, Conventional PID Controller and Fuzzy Logic Based Controller implemented on first order and second order systems. The step input is taken as the reference input to obtain the transient and steady state response of the systems. The terms like peak time, maximum overshoot, settling time, rise time, Sum Squared Error (SSE), Integral Absolute Error (IAE) and Integral Absolute Time Multiplied Error (IATE) and sum square error are calculated and compared.

General Terms

PD controller, PID controller, Fuzzy logic controller

Keywords

Fuzzy logic controller, scaling factor, non linear Proportional Derivative controller, Proportional Integral Derivative controller

1. INTRODUCTION

PID Control schemes based on classical control theory are widely used in industry because of simple structure, reliable operation and near optimal performance. Thus, PID controller is the most common form of feedback. The controllers consist of many different forms. However, an important aspect of PID Controller is that they need to be tuned properly. Offline method such as Ziegler- Nichols method is used to tune the PID or an expert human operator can manually tune the PID parameters. As we know practically the system being controlled are subjected to disturbances and parameter variations in the system also take place [1]. Thus the controller needs to be tuned online, an expert human operator can also do the same but any error on the part of human operator cannot give us poor performance but also destroy or damage the system. So the need of PID Controller arises when parameters can be tuned automatically.

PID Controller primarily comprises of three parameters which influence the controller action are Proportional gain Derivative gain and Integral gain. The proportional gain block generates a control signal which is proportional to the error. Derivative block generates a control signal depending on the rate of change of error. Integral block generates a control signal depending on the summation of past mistakes [1,2]. Unlike PD controllers, PID-type FLCs are suitable mainly for systems and systems with large dead time.

The transfer function of the most basic form of PID controller is

$$C\ (S) = K_P + \frac{K_i}{s} + K_D S$$

Where Kp = Proportional gain, Ki = Integral gain and K_D= Derivative gain.

The control µ from the controller to the plant is equal to the Proportional gain (KP) times the magnitude of the error plus the Integral gain (Ki) times the integral of the error plus the Derivative gain (KD) times the derivative of the error.

$$\mu = Kpe + Ki\int edt + Kd\,\frac{de}{dt}$$

The output Scaling Factor of FPIDC is modified on-line by a gain factor, which is further multiplied by a fixed factor chosen empirically. In this work 49 fuzzy rules defined on e and ce, and derived from the process control engineering knowledge. Thus, the on-line adjusted output gain factors of the proposed FPIDC are expected to improve the close-loop performance, since it incorporates the dynamics of the process. The performance of the proposed FPIDC is tested by simulation experiments on a number of second-order systems with dead-time. Results show that the proposed PID controller with Dead Time outperforms its conventional fuzzy PD controller (FPDC).

Fuzzy logic controllers (FLCs) are used successfully in a number of difficult processes and are being able to handle non-linear and high-order systems [7].Fuzzy logic controllers (FLCs) have many values which are appropriate and vague boundary. The variables in fuzzy logic system may have any value in between 0 and 1 and hence this type of logic system is used to address the values of the variables those lie between completely truth and completely false. Practical processes are usually nonlinear in nature and associated with dead time and their parameters may change with time and ambient conditions. The variables are called linguistic variables and each linguistic variable is described by a membership function which has a certain degree of membership at a particular instance. System based on fuzzy logic carries out the process of decision making by incorporation of human knowledge into the system.

There are five steps involved in the implementation of Fuzzy Logic controller (i) fuzzification, (ii) applying fuzzy operators to IF part of the rule, (iii) applying implication operator to evaluate output i.e. THEN part of the rule, (iv) aggregation of the outputs of all rules in the rule base, (v) defuzzification of fuzzy output to obtain crisp output. Error in output (e) and change in error in output (ce) are normally taken as the inputs of the fuzzy controller [7]. Such FLCs with fixed values of Scaling factors and simple Membership Functions are not expected to provide good control performance. Fuzzy controllers are known to be more effective in solving practical control problems. Theoretical study and practical applications of fuzzy control have advanced significantly in past few years[3,5,6].

The aim of this paper is that it shows the dynamics response of PID Controller and PD Controller with the design of the fuzzy logic controller to control the Transient Response and Steady State Response with different values of Dead Time.

Fig 1 shows the block diagram of the proposed FPIDC. Next we present its various design aspects.In fuzzy based PID controller, Proportional gain K_p and Integral gain K_i and Derivative gain K_d are used to produce controlled output. There are two inputs error (E) and change in error (CE) to fuzzy controller and a single output U as in the Conventional Fuzzy Controller. The seven rules are used for the computation of output U. The universe of discourse each variable E, CE and U is [-2,2]. For input variables there are seven Membership Functions named as Negative Small (NS), Negative Medium (NM), Negative Large (NL), Zero (ZR), Positive Small (PS), Positive Medium (PM) and Positive Large (PL) and for output variable there are seven membership functions named as Negative Small (NS), Negative Medium (NM), Negative Large (NL), Zero (ZR), Positive Small (PS), Positive Medium (PM) and Positive Large (PL).

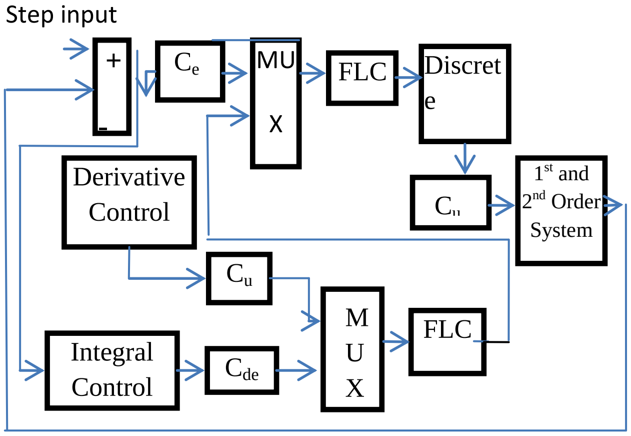
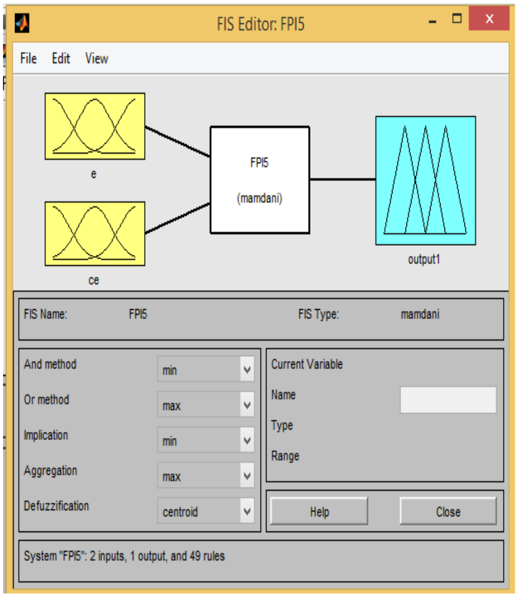


Figure 1: Block Diagram of Fuzzy Logic Based PID Controller

A change in gain factor affects all fuzzy rules [10]. So these gain factors for fuzzy PID controller are calculated in terms of C_u, C_e and C_{de}. From these gain variables proportional and integral gains are calculated and further tuned by hit and trial method.

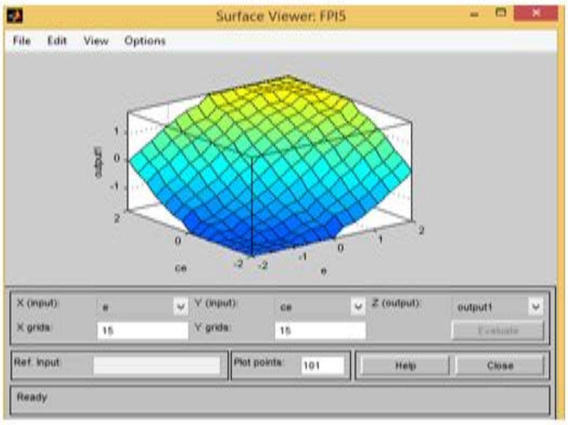


FIS Name: FPI5
FIS Type: mamdani
And method: min
Or method: max
Implication: min
Aggregation: max
Defuzzification: centroid
System "FPI5": 2 inputs, 1 output, and 49 rules

Figure 2: Membership Function with error (e), change of error(ce) and Process control (µ)

To study the effectiveness of our proposed scheme we perform simulation experiments on a wide variety of second order systems with different dead time.

PL	PM	PS	ZR	NS	NM	NL	
ZR	NS	NM	NL	NL	NL	NL	NL
PS	ZR	NS	NM	NL	NL	NL	NM
PM	PS	ZR	NS	NM	NL	NL	NS
PL	PM	PS	ZR	NS	NM	NL	ZR
PL	PL	PM	PS	ZR	NS	NM	PS
PL	PL	PL	PM	PS	ZR	NS	PM
PL	PL	PL	PL	PM	PS	ZR	PL



X (input): e
Y (input): ce
Z (output): output1
X grids: 15
Y grids: 15
Plot points: 101
Ready

Figure 4. Control surface of the proposed FPIDC

Results of different systems with varying dead-time under both set-point change and load disturbance are observed for

FPIDC and FPDC. Dead time introduce an additional lag in the system phase, thereby decreasing the phase and gain margin of the transfer function, making the control of these systems more difficult [3,4, 9].Performance comparison among various fuzzy controllers are made with respect to a number of performance indices, such as Maximum overshoot (%OS), Settling time (t_s), Rise time (t_r) and Integral Absolute Error (IAE). Mamdani type inferencing and height method of defuzzification are used.

2. RESULTS

In this paper, different values of dead time are considered like L=0.1, 0.2, 0.3 and 0.4. Transient and steady-state responses with L= 0.2 and L= 0.4 for set-point change and load **disturbance are shown in Figures. It clearly shows that the** performance of FPDC becomes degraded for a large change in dead-time. In such cases proposed FPIDC maintains a satisfactory level of performance when combined with PID controllers. Moreover, the FPIDC that uses additional 49 fuzzy rules for gain adjustment provides almost similar performance, which justifies the effectiveness of the proposed scheme.

Table 1.Comparison of Performance of Controller for First Order System and Second Order System

Dead Time (L)	Controller	Maximum Overshoot (OS%)	Settling Time (t_s)	Rise Time (t_r)	Integral Absolute Error (IAE)
0.1	FPD	0.55	39.53	4.94	32.89
0.1	FPID	0.04	4.80	3.74	14.01
0.2	FPD	0.58	45.62	5.48	32.22
0.2	FPID	0.05	4.80	3.75	13.99
0.3	FPD	0.51	30.67	5.94	31.68
0.3	FPID	0.06	5.62	3.75	13.35
0.4	FPD	0.52	29.54	5.53	31.11
0.4	FPID	0.06	5	3.75	13.44

2.1 Conventional PD Controller with Dead Time 0.1

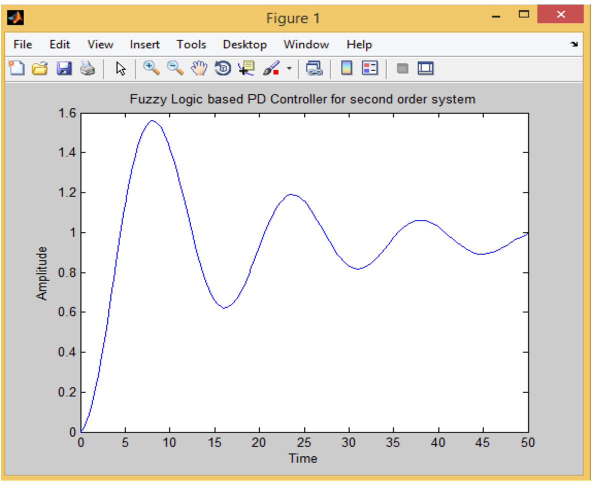


Figure 5.1 Transient Response of Fuzzy Based PD Controller with Dead Time 0.1

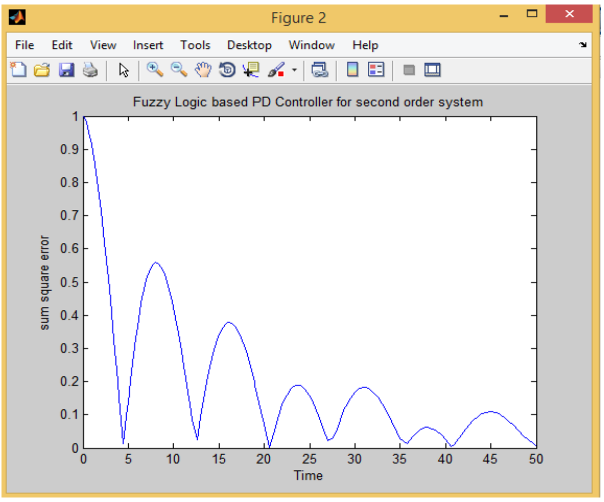


Figure 5.2 Steady State Response of Fuzzy Based PD Controller with Dead Time 0.1

The transient response and steady state response of the system is shown in Figure 5.1 and 5.2. It is clear from the response that rise time of the system is 4.9 sec. The response reaches to its maximum value at 5.5 sec. The maximum overshoot produced by the response is 0.55 and settled down at 39.53 sec. The steady state responseplot shows the variation of sum squared error with respect to time. In initial conditions the sum square error is one then it reduces steadily but after about 4.9 seconds it increases again due to undershoot. Finally, the overshoot decreases and error reduces to almost zero and system reaches its steady state response when time reaches to 50 sec. The integral absolute error (IAE) is 36.89.

Conventional PID Controller with Dead Time 0.1

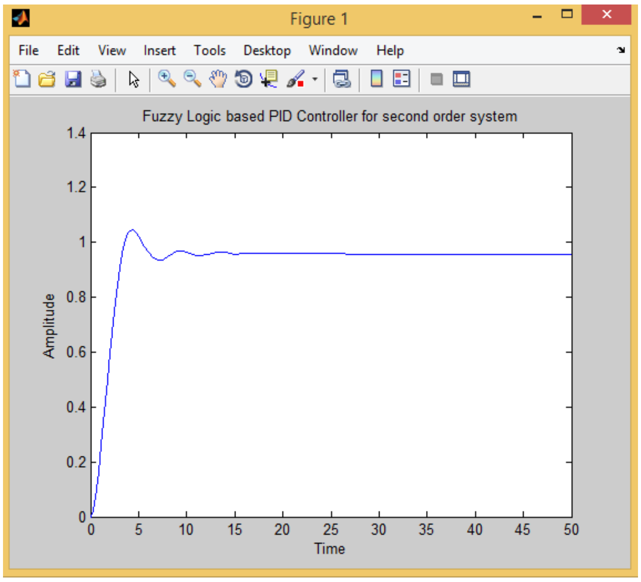


Figure 5.3 Transient Response of Fuzzy Based PID Controller with Dead Time 0.1

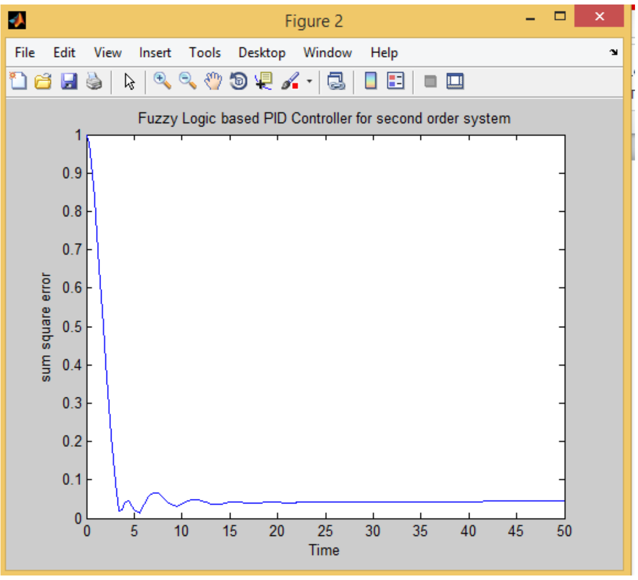


Figure 5.4 Steady State Response of Fuzzy Based PID Controller with Dead Time 0.1

The transient response and Steady State Response of the system are shown in Figure 5.3 and 5.4. It is clear from the response that rise time of the system is 3.74 sec. The response reaches to its maximum value at 4.65 sec. The maximum overshoot produced by the response is 0.04 and settled down at 4.80 sec. The steady state plot response shows the variation of sum squared error with respect to time. In initial conditions the sum square error is one then it reduces steadily but after about 6 seconds it increases again due to undershoot. Finally, the overshoot decreases and error goes to above to zero and system reaches its steady state response when time reaches to 14 sec. The integral absolute error (IAE) is 14.01.

Conventional PD Controller with Dead Time 0.4

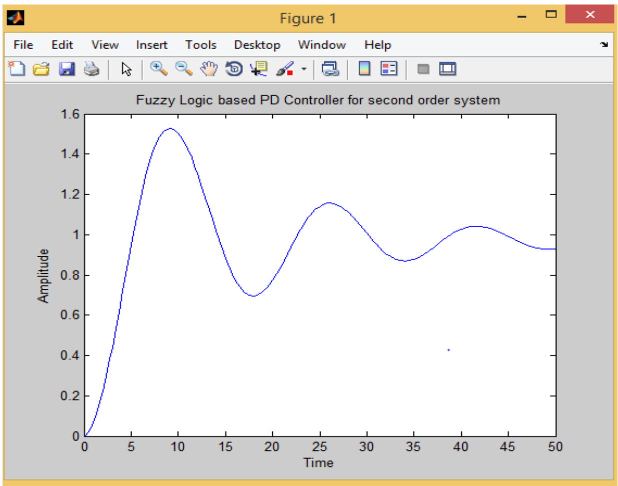


Figure 5.5 Transient Response of Fuzzy Based PD Controller with Dead Time 0.4

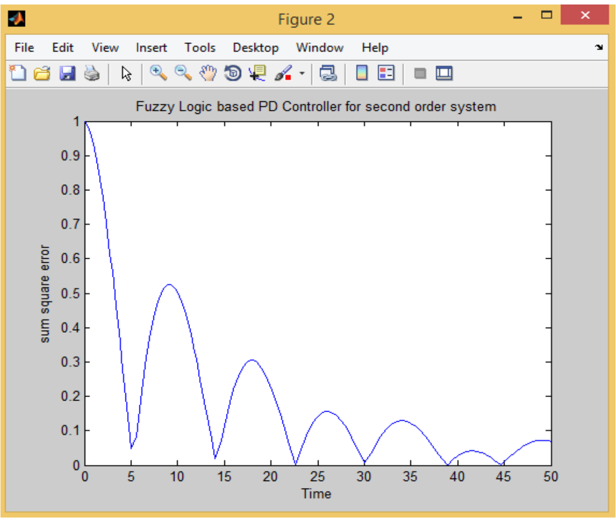


Figure 5.6 Steady State Response of Fuzzy Based PD Controller with Dead Time 0.4

The transient response and steady state response of the system are shown in Figure 5.5 and 5.6. It is clear from the response that rise time of the system is 5.5 sec. The response reaches to its maximum value at 5.8 sec. The maximum overshoot produced by the response is 0.52 and settled down at 29.54 sec.The steady state response plot shows the variation of sum squared error with respect to time. In initial conditions the sum square error is one then it reduces steadily but after about 5 seconds it increases again due to undershoot. Finally, the overshoot decreases and error reduces to almost zero and system reaches its steady state response when time reaches to 50 sec. The integral absolute error (IAE) is 31.11.

Conventional PID Controller with Dead Time 0.4

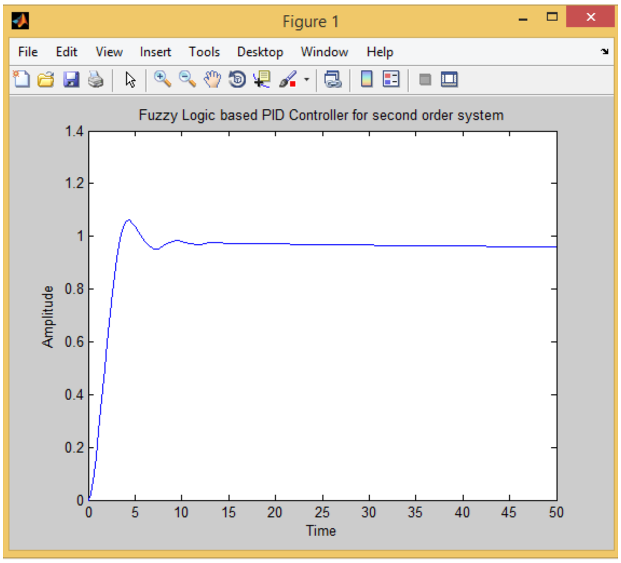


Figure 5.7 Transient Response of Fuzzy Based PID Controller with Dead Time 0.4

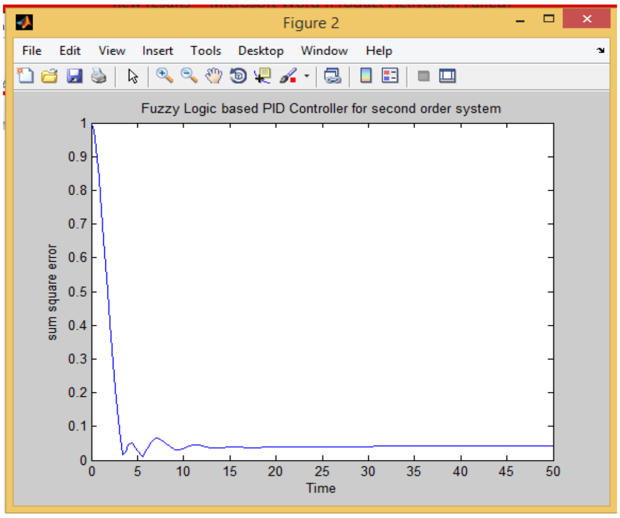


Figure 5.8 Steady State Response of Fuzzy Based PID Controller with Dead Time 0.4

The transient response and steady state response of the system are shown in Figure 5.7 and 5.8. It is clear from the response that rise time of the system is 3.75 sec. The response reaches to its maximum value at 4.7 sec. The maximum overshoot produced by the response is 0.06 and settled down at 5 sec. The steady state response plot shows the variation of sum squared error with respect to time. In initial conditions the sum square error is one then it reduces steadily but after about 4.6 seconds it increases again due to undershoot. Finally, the overshoot decreases and error reduces to almost zero and system reaches its steady state response when time reaches to 24 sec. The integral absolute error (IAE) is 13.44.

3. CONCLUSION AND FUTURE SCOPE

We proposed a fuzzy Based scheme for PD-type and PID-type fuzzy logic controller which is tuned online by adjusting its output gain parameters depending on the process trend. The most important feature of the proposed scheme is that it is process independent. FPIDC has been tested on a wide variety of second-order systems with different dead time. In each case, FPIDC provided remarkably improved performance compared to FPDC and its output is improved in terms of maximum overshoot and integral absolute error is reduced to great extent. Robustness of FPIDC has been established by considering the same rule-base and MFs for all the examples with different values of dead time.

The output becomes better by varying different scaling factors. There have been intensive developments in this field. There is a still scope for future improvements. In the future, 50

the Neural Network, the combination of Fuzzy and Neural Network and Adaptive-Neuro Fuzzy Inference System (ANFIS) techniques will use for better results. Neuro-fuzzy PID controller can be designed by the implementation of neural network to fuzzy PID controller. There are several areas of investigation which needs to be explored. For systems with high order dominant dynamics, PID control is generally not adequate and accordingly upgrading the existing PID design that handle dominant high frequencies needs to be further explored. This will lead to higher order and more complex controllers. The simple structure of PID controllers limits their performance and systems with large delays or with complex dynamics are hard to control with these controllers

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