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DESIGN AND IMPLEMENTATION OF FUZZY LOGIC CONTROL BASED SPEED CONTROL OF INDUSTRIAL CONVEYOR

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ABSTRACT

This article presents a methodology and verification for implementation of a rule-based fuzzy logic controller applied to a closed loop DC motor speed control. The designed Fuzzy Logic Controller's performance is compared against with that of a PI controller. The importances of the Fuzzy Logic Controllers (FLCs) over the conventional controllers are: They are economically advantageous to develop and implement, a wider range of operating conditions can be covered using FLCs, They are easier to adapt in terms of natural language. For Voltage / Speed control of the conveyor, a reference speed has been used and the control architecture includes rules. These rules portray a nonchalant relationship between two inputs and an output, all of which are nothing but normalized voltages.

Keywords: set speed, conveyor, motor, fuzzy, proportional, integral, derivative.

INTRODUCTION

A conveyor system is a common piece of mechanical handling equipment that moves materials from one location to another. Conveyors allow quick and efficient transportation for a wide variety of materials, which make them very popular in the material handling and packaging industries. Many kinds of conveying systems are available, and are used according to the various needs of different industries. There are chain conveyors (floor and overhead) as well. Chain conveyors consist of enclosed tracks, I-Beam, towline, power and free, and hand pushed trolleys. In a batch process which involves conveyors, slowing down or speeding up of conveyors due to added loads or reduced loads can cause a timing miss and the next stage in the process may miss its role. To avoid this, the conveyor speed has to be defined for each range of load, this involves complications. So we designed a controller for controlling the speed of the conveyor for varying load

Direct Current (DC) motors are being widely used in many industrial applications such as electric vehicles, heavy load conveyors, steel rolling mills, electric cranes and robotic manipulators due to precise, wide, simple and continuous control characteristics. The development of high performance motor drives is very important in industrial as well as other purpose applications. Generally, a high performance motor drive system must have good dynamic speed command tracking and load regulating response. Traditionally rheostat armature control method was widely used for the speed control of low power DC motors. However the controllability, cheapness, higher efficiency, and higher current carrying capabilities of static power converters brought a major change in the performance of electrical drives.

Many varieties of control schemes such as P-Proportional, PI-Proportional Integral, PID- Proportional Integral derivative, adaptive and FLC-fuzzy logic controllers have been developed for speed control of DC motors. As PID controllers require exact mathematical modeling, the performance of the system is questionable if there is parameter variation. In recent year's neural network controller (NNC) were effectively introduced to improve the performance of nonlinear systems. The proposed controller systems consist of multi-input fuzzy logic controller for the speed control.

CONVEYOR CONTROL CONSTRAINTS

a) Non linearity in motor
b) Variable and unpredictable inputs
c) Noise propagation along a series of unit processes
d) Unknown parameters
e) Changes in load dynamics

Major problems in applying a conventional control algorithm in a speed controller are the effects of non-linearity in a DC motor. The non-linear characteristics of a DC motor such as saturation and friction could degrade the performance of conventional controller. Many advance model-based control methods such as variable structure control and model reference adaptive control have been developed to reduce these effects. However, the performance of these methods depends on the accuracy of system models and parameters. Generally, an accurate non-linear model of an actual Dc motor is difficult to find and parameter values obtained from system identification may be only approximate values. Even the PID controllers require exact mathematical modeling.

ADVANTAGES OF USING FUZZY TECHNIQUE

a) Inherent approximate capability
b) High degree of tolerance
c) Smooth operation
d) Reduce the effect of Non-linearity Fast adaption
e) Learning ability

Emerging intelligent techniques have been developed and extensively used to improve or to replace conventional control technique because these techniques do not require a precise model. One of intelligent

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technique, fuzzy logic by Zadeh is applied for controller design in many applications. A fuzzy logic controller (FLC) was proved analytically to be equivalent to a non-linear PI controller when a non-linear defuzzification method is used. Also, the result from the comparisons of conventional and fuzzy logic control techniques in the form of a FLC and fuzzy compensator showed fuzzy logic can reduce the effects of non-linearity in a DC motor and improve the performance of a controller.

MOTIVATION

The main idea is to reduce the time lost in slowing down of conveyors due to added loads. In a batch process which involves conveyors, slowing down of conveyors due to added loads or reduced loads can cause a timing miss and the next stage in the process may miss its role. To avoid this, the conveyor speed has to be defined for each range of load, this involves complications. Other way to solve this problem is to dedicate a controller for speed of the conveyor. So, we can control the speed irrespective of load.

SYSTEM DESCRIPTION

This is the general speed control block diagram of a DC motor. The basic components of this block are summer, Controller, Motor Driver, Target Motor and Sensor. The first input to the summer is set speed, the desired speed at which the motor is expected to run. The second input to the summer is the feedback signal, the current speed of the motor. The difference between these two inputs is called as Error Signal (E).This E is given to the controller, the controller could be of any type i.e.- P, PI, PD, PID, FLC, FPID etc.. The controller reads the error signal E and produces respective output signal, this signal is called as Controller Output (CO). The CO then reaches the Motor Driver; the motor driver produces an output which is proportional to the control signal, which can drive the motor accordingly.

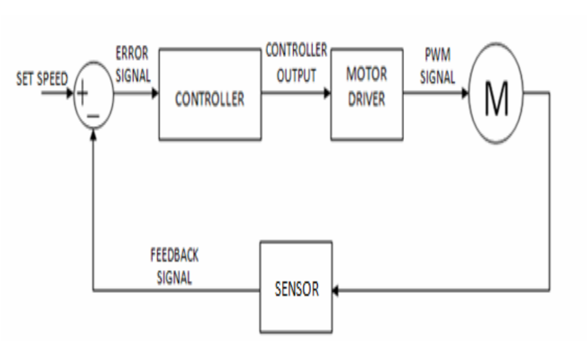

Figure-1. General block diagram of controller.

The sensor measures the motor speed and changes it to a summer readable format and it becomes the second input of the summer. This process continues till the motor reaches the set speed i.e. when the error becomes zero. The parameter of the motor used for simulation purpose is given in Table-1.

DC MOTOR

Table-1. DC motor parameters

PARAMETER	VALUE
Moment of inertia of the rotor	J = 0.01Nm/rad/s 2
Damping of the mechanical system	b = 0.1Nm/rad/s
Armature resistance	Ra = 1Ω
Inductance	La = 0.5Mh
Electromotive force constant	K = 0.05 Nm / A

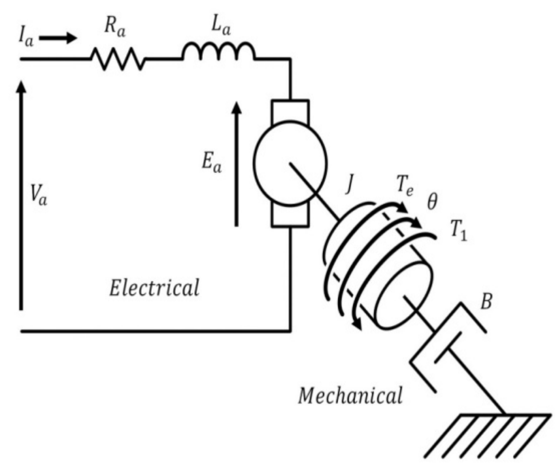

Figure-2. DC motor.

The input to the system is armature voltage V in volts. Variables measured are velocity of the shaft in rotations per minute. The motor torque is proportional to the armature current i. The proportionality constant is K.

$$T = k_i \quad (1)$$

The back electromotive force V_b, can be equated to velocity by:

$$V_b = k\,(d\theta/dt) \quad (2)$$

From the DC motor Figure the following equations can be derived with the help of Newton's law and Kirchhoff's law.

$$J\frac{d^2\theta}{dt^2} + b\frac{d\theta}{dt} = k_i \quad (3)$$

$$L\frac{di}{dt} + Ri = V - k\frac{d\theta}{dt} \quad (4)$$

Applying Laplace transform to equations (3) and (4) we get:

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$$Js^2\theta(s) + bs\theta(s) = k_1(s) \quad (5)$$

$$LsI(s) + RI(s) = V(s) - ks\theta(s) \quad (6)$$

From equation (6) we can write I(s):

$$I(s) = \frac{V(s) - ks\theta(s)}{R + Ls} \quad (7)$$

Putting (7) in (5) we get

$$JS^2\,\theta(s) + bs\theta(s) = k\frac{V(s) - Ks\theta(s)}{R + Ls} \quad (8)$$

From Figure-2, it is easy to see that the transfer function from the input voltage, V(s), to the Velocity.

$$G(s) = \frac{\theta(s)}{V(s)} = \frac{K}{s[(R + Ls)(Js + b) + K^2]} \quad (9)$$

Transfer function of the dc motor is

$$G(s) = \frac{W(s)}{V(s)} = \frac{k}{(R + Ls)(Js + b) + K^2} \quad (10)$$

$$G(s) = \frac{k}{JLs^2 + (JR + bL)s + K^2} \quad (11)$$

PID CONTROLLER

PID controllers are most popular and widely used controllers in industries for any kind of control system. The difference between the desired speed and the output feedback is passed as input into the PID controller subsystem. The PID Controller subsystem contains the proportional gain scaling factor (Kp), the derivative gain scaling factor (Kd) and the integral gain scaling factor (Ki). The derivative gain factor and the integral gain factor are both passed through a derivative block and an integral block respectively before being summed up with the proportional gain factor. The output of the PID controller subsystem is the summed up value of proportional, integral and derivative gain.

PROPORTIONAL

It produces an output control signal which is directly proportional to the error signal and the proportionality constant is K_p.

$$P_{OUT} = K_p \quad (12)$$

Where p_{out} = proportional block output
K_p = proportionality gain

INTEGRAL

It is the sum of error occurred over time and gives the accumulated value that should have been corrected previously. This accumulated error is then multiplied with integral gains scaling factor (K_i)

$$I_{OUT} = K_I \sum_{i=0}^{n} E\Delta T \quad (13)$$

Where I_{out} = integral block output
K_i = integral gain
E = error signal

DERIVATIVE

This unit of controller reduces the overshoot produced by integral unit and it improves the controller process stability.

$$D_{OUT} = K_d\left(\frac{E_n - E_{n-1}}{\Delta T}\right) \quad (14)$$

Where D_{out} = derivative block output.
K_d = derivative gain.
E_n = error signal.

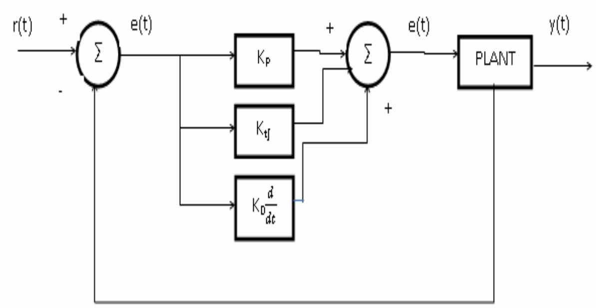

Figure-3. Block diagram of pid controller.

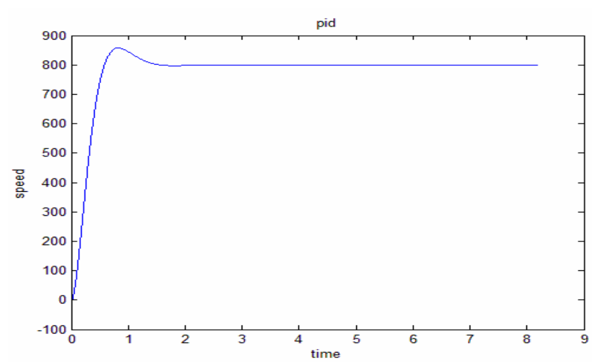

Figure-4. PID output.

FUZZY LOGICCONTROLLER

Fuzzy logic is an easy approach to control engineering problems; it mimics how a person would take decisions but really faster. Fuzzy logic is a simple rule based "IF A and B then C" method to solving problem rather than attempting to model a system mathematically. There are specific components characteristic of a fuzzy controller to support a design procedure. The basic block

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diagram of fuzzy logic control consists of Fuzzifier, Defuzzifier, Knowledge base, Decision making unit. Fuzzifier and Defuzzifier are used to communicate with the real world. Knowledge base is used for defining set of rules. Decision making unit is responsible for taking decision based on given inputs and set of rules. The linguistic variables are defined as {NB,NM, NS, Z, PS,PM, PB}, where NB means negative big, NM means negative medium, NS means negative small, Z means zero, PS means positive small and PM means positive medium PB means positive big. Figure shows the controller structure.

FUZZIFIER

The inputs are most often hard or crisp measurement from the sensor (speed) rather than linguistic. This process is called as fuzzification, which converts a piece of input data to degrees of membership by a lookup in one or several membership functions. The fuzzification block matches the input data with the conditions of the rule to determine. There is a degree of membership for each linguistic term that applies to the input variable.

DEFUZZIFIER

Defuzzification is a process of converting linguistic variables into crisp values that can be understood by system under control. FLC has 2 inputs-Errors (E) and Change in Error (CE) and one output connected to the motor driver (L293D).

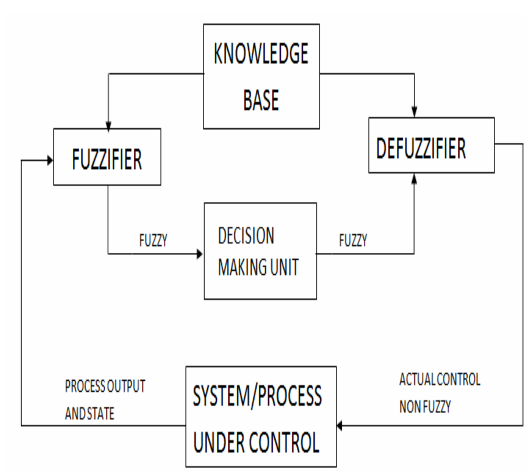

Figure-5. Block diagram of fuzzy controllers.

KNOWLEDGE BASE

The collection of rules is called a knowledge base. The rules are in "If then" style. There are two "IF" sides and the "THEN" side is called conclusion. The system then executes the rules for two inputs, ie error and change in error. In a rules based controller the rules are stored in a natural language. The number of rules based on the system demand. If the system has to be very accurate, then using more number of rules is recommended. The rules are shown in Table-2.

Table-2. Fuzzy rule.

CE/E	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZO
NM	NB	NB	NB	NM	NS	ZO	PS
NS	NB	NB	NM	NS	ZO	PS	PM
ZO	NB	NM	NS	ZO	PS	PM	PB
PS	NM	NS	ZO	PS	PM	PB	PB
PM	NS	ZO	PS	PM	PB	PB	PB
PB	ZO	PS	PM	PB	PB	PB	PB

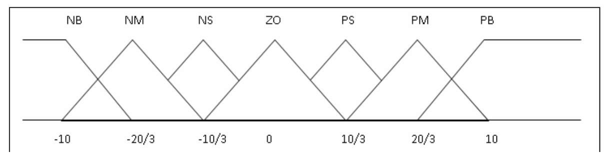

Figure-6. Membership function for error, change in error and output.

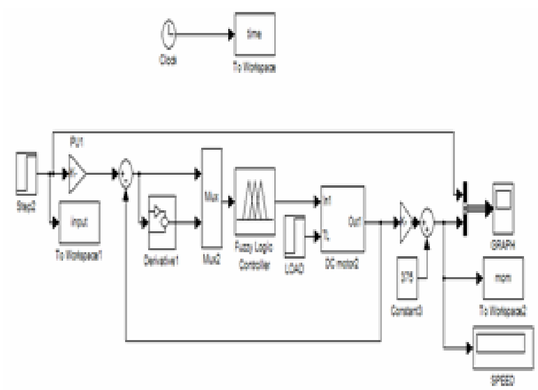

Figure-7. Block diagram of Fuzzy logic controller.

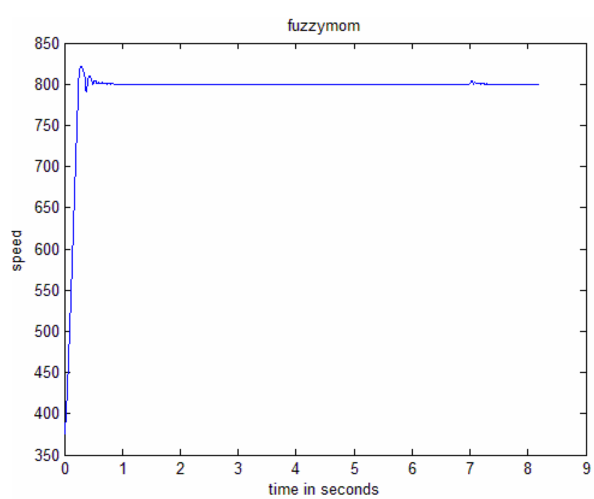

Figure-8. Fuzzy MOM output.

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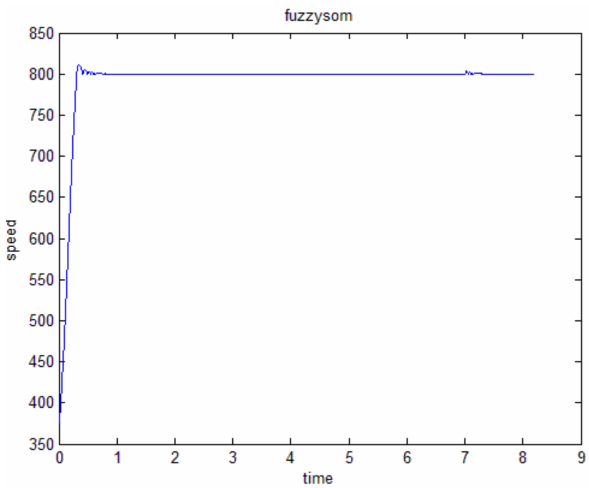

Figure-9. Fuzzy SOM output.

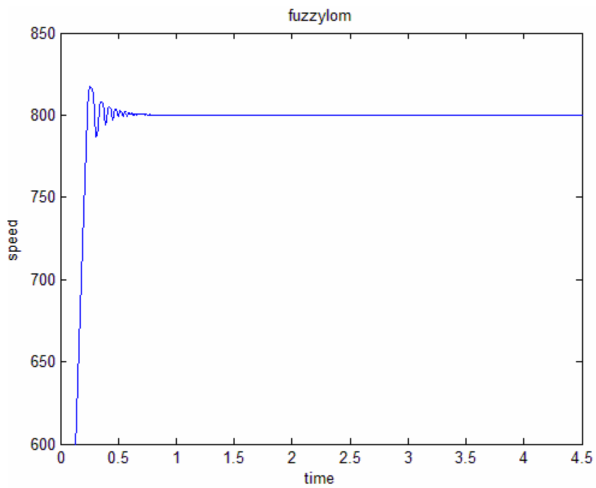

Figure-10. Fuzzy LOM output.

Table-3. Response of different controllers.

Parameters	PID	Fuzzy LOM	Fuzzy MOM	Fuzzy SOM
Rise time (ms)	603.7481	629.8985	649.9503	650.0068
Settling time (ms)	1.4500e+ 003	0.65e+00 3	0.75e+003	0.8e+003

It can be understood from the above graphs that while using Fuzzy logic Controller the overshoots obtained are smaller when compared to PID controller. The settling time is also less in case of the FLC, but the rise time is larger. The FLC, however shows a better response when the reference speed is changed. It tends to approach the new set speed faster. The PID controller doesn't reach a steady state but the FLC attains a steady state but it is very close to the set speed. The fuzzy logic controller with LOM defuzzification method produces the most efficient result. When the set speed is 1200 it settles around 1190 to 1215, which is acceptable and it doesn't cause a disturbance to the system.

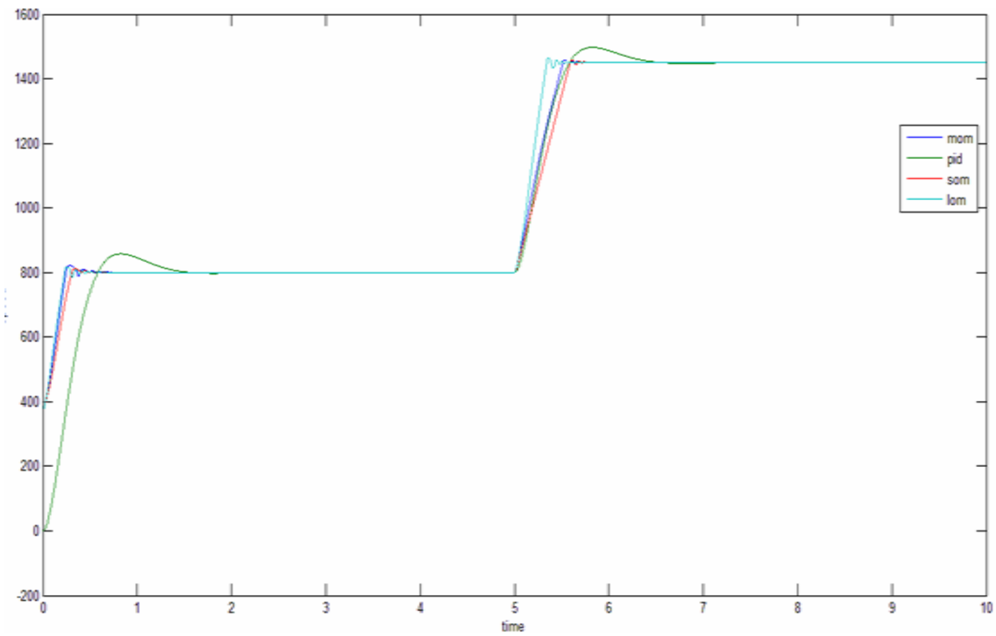

Figure-11. Comparison of different fuzzy methods.

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The response plots show that while using Fuzzy Logic Controller oscillations occur during starting while the PID controller doesn't show any such behavior.

This is because the FLC is based on random knowledge of data. Then controller provides a better response after some time as the controller needs some time to learn the system and adjust according to the knowledge developed by the user.

HARDWARE IMPLEMENTATION

The same system was implemented on a conveyor model using Arduino through Simulink. A separate atmega 328 chip was dedicated to find the speed of the running conveyor. The chip was coded to read the input from the IR sensor, which produces 6 pulses per rotation of the conveyor wheel. The code manipulates this signal and produces the output in RPM. This is then put across a digital filter to eliminate noise and it is normalized within the Simulink. The summer calculates the error between the desired speed and current speed, this error and its derivative is given to the multiplexor, which is then given to the Fuzzy logic Controller. The FLC makes decision according to the knowledge base and decision making logic. Here, the FLC's output range is set from 0 to 255, because the Arduino considers 0 as 0v and 255 as 5v. This PWM signal is given to the motor driver L293D. So that, the motor speed can be controlled by changing the power given to the armature, Pulse Width Modulation is a well-known method to do this task. In this technique, the power is controlled by applying pulses of variable width by changing pulse width of power. With the pulse width small, the applied voltage to the armature is low. When the pulse width is large, the power across the armature is high.

Figure-12. Real time encoder.

CONCLUSIONS

The FLC used in this project has both advantages and drawbacks. But these drawbacks i.e. (i) achievement of only near to exact speed after change in reference speed and (ii) high rise time, can be reduced by fine tuning and refining the member ship functions.

Figure-13. Conveyor setup.

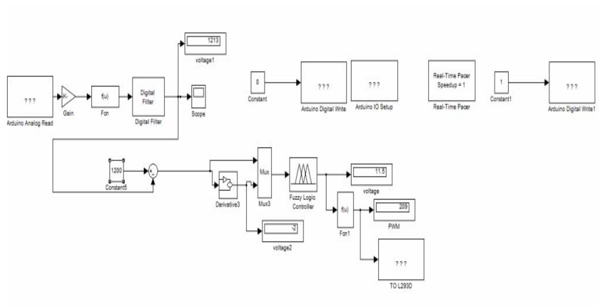

Figure-14. System implementation.

We have used a hybrid of trapezoidal and triangular membership functions for both input and output. To further improve the response we can choose Gaussian membership functions. The objectives were met in both software simulations as well as hardware implementations.

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