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Adaptive fuzzy logic based controller for a position control system

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Abstract

High performance position control can be obtained with dc servomotors and actuators by using efficient control strategies. For precise control of position, the control strategy employed should result in fast control of the output, with minimum overshoot and least steady state error. The advancement of control theory over the last 30 years resulted in a huge choice of control schemes, given a plant or a system to be controlled. Despite this, traditional PID (proportional integral and derivative) control scheme is the popular choice for implementation in industrial environment, as this scheme is simple and easy to implement and its design does not require an exact knowledge of the controlled plant dynamics. Fuzzy logic is recently finding wide popularity in various applications that include management, economics, medicine and process control systems. This paper presents the simulation and experimental results of the adaptive fuzzy logic control scheme proposed for a position control system, with cost-effective, real time implementation as the main objective. Traditional PID control and more recent fuzzy logic control schemes have been used for the studies. It is demonstrated both by simulation and experimental implementation on a prototype system that fuzzy logic control can provide better control, does not require mathematical modelling of the plant and yields better disturbance rejection properties.

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1 Introduction

High performance position control can be obtained with dc servomotors and actuators by using efficient control strategies. For precise control of position, the control strategy employed should result in fast control of the output, with minimum overshoot and least steady state error. The advancement of control theory over the last 30 years resulted in a huge choice of control schemes, given a plant or a system to be controlled. Despite this, traditional PID (proportional integral and derivative) control scheme is the popular choice for implementation in industrial environment, as this scheme is simple and easy to implement and its design does not require an exact knowledge of the controlled plant dynamics. Tuning a PID controller is usually achieved either by the Ziegler-Nichols method, Ziegler et.al.,[1], which requires ultimate gain and ultimate period and does not necessarily give very good reponse, or by optimal tuning, Harris et.al.,[2], which needs a mathematical model of the system. Several other schemes have been proposed in the recent years for the automatic tuning of PID controllers. Among others, relay feedback by Astrom et.al.,[3], approximate system identification by Hang et. al.,[4], cross correlation by Hang et.al.,[5], and expert systems by Astrom et.al.,[6] and Acosta et. al.,[7], provide ways to find near-optimal settings for the controller parameters. With the introduction of fuzzy set theory by Zadeh [8,9], as a tool for controlling complex and ill-defined systems, many researchers have used the theory to tune the P, I and D parameters of the controller and have demonstrated the potential of this type of controller. Some of the work reported in the last few years using fuzzy logic approach includes, fuzzy logic based input and output mapping factors method by Wong et. al., [10], knowledge-based PID auto- tuner by Lee et. al., [11], and a combination of fuzzy logic ideas and expert sytem approach by Acosta et. al.,[12]. All these methods proposed, though efficient, performance wise, make the real time implementation difficult either due to the lack of availability of appropriate hardware, or require expensive hardware set ups in order to match the theoretical performance predictions of the proposed schemes. In this paper, we examine an experimental and simple auto tuning approach using fuzzy logic ideas for tuning the controller gains and compare its performance with a standard ZN-tuned controller. Percentage overshoot, rise time and settling time has been used for comparison. The objective of the conducted study was to make the proposed scheme simple and similar to the traditional ZN-tuned controller, with an additional objective of ease and cost-effectiveness in practical implementation, making fuzzy-logic based schemes equally popular choice as ZN-based technique in the industrial environment A laboratory model position control system by Feedback instruments ltd. has been used as a case study The performance of the proposed scheme and the comparison with

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the established ZN tuning technique is assessed through computer simulation and the experimental verification was carried out using off the shelf low cost microcontrollers.

A brief review of fuzzy logic concepts is given in the next section. Section 3 gives a brief review of fuzzy logic controller design methods and fuzzy logic method used for tuning the controller is explained in section 4. Section 5 gives some sample simulation and experimental results and the paper concludes with some suggestions and comments for real time implementation of fuzzy logic controllers.

2 Fuzzy sets and fuzzy systems

Fuzzy logic is recently finding wide popularity in various applications that include management, economics, medicine and process control systems. Although it is not the purpose of this paper to provide fundamentals of fuzzy logic, which may be found in other works, we shall introduce it briefly with control systems perspective. Fuzzy theory was introduced by Zadeh [8], around twenty seven years ago, but only recently its application has received large momentum. Fuzzy logic, unlike the crisp logic in Boolean theory, deals with uncertain or imprecise situations. A variable in fuzzy logic has sets of values which are characterized by liguistic expressions, such as SMALL, MEDIUM, LARGE etc.. These linguistic expressions are represented numerically by fuzzy sets (sometimes referred to as fuzzy subsets). Every fuzzy set is characterized by a membership function, which varies from 0 to 1, (unlike 0 and 1 of a Boolean set). Although fuzzy theory deals with imprecise information, it is based on sound quantitative mathematical theory. A fuzzy control algorithm for a process control system embeds the intuition and experience of an operator, designer and researcher. The control does not need accurate mathematical model of a plant, and therefore, it suits well to complex industrial processes, like non-linear processes with considerable time delays, processes with wide ranging time constants and asymmetric gain characteristics, processes operating under the influence of strong non-stationary noise and the processes which are conventionally controlled by human operators due to their complexity. These complex processes have mathematical models which are hard to define. Tuning a controller for such a process is usually done using empirical techniques like ZN tuning and the operator adjusts the controller settings by monitoring the process behaviour. His own judgement about the process is also used as further input to the tuning process. In the work reported here we used fuzzy logic to fine tune the controller gains, which is ZN-tuned to start with, and fine tuned with a fuzzy logic approach if it does not perform satisfactorily due to changes in process dynamics and the environment. In fact, relation between fuzzy controller and the conventional Proportional + Integral (PI) controller has been established by Buckley and Yang [13]. They showed that for a general fuzzy controller employing linear fuzzy rules, as the number of rules grow, the defuzzified controller output becomes a linear function of the input. In particular, the fuzzy controller output is approximately the same as the conventional PI controller. The fine tune strategy was planned with this background and is explained in few section.

3. Design of fuzzy tuned controller

The basic fuzzy logic control configuration is as shown in figure 1. The fuzzy controller studied in this paper accepts fuzzified variables corresponding to error and change in error as input and determines its control action based on compositional rule of inference. Figure 2 shows a schematic diagram of this controller. The main parts of such a controller are

1. Defining input/output variables;
2. Converting those variables to a fuzzy set,
3. Determining the rule base and
4. Transforming back the fuzzy output into crisp control action.

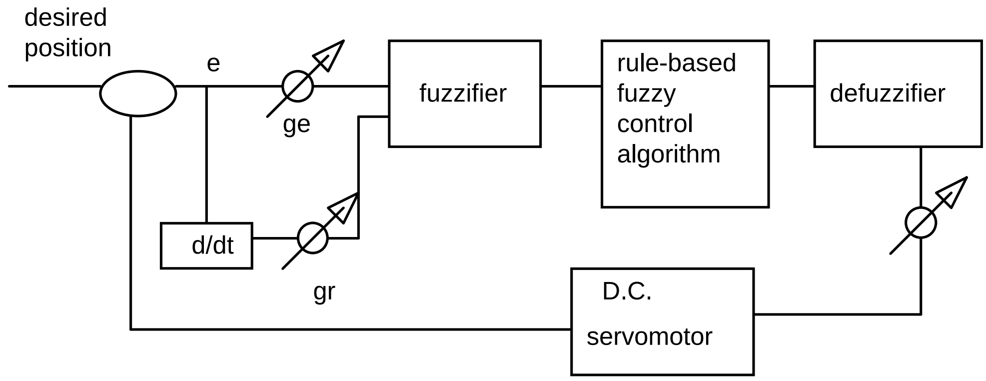

Figure 1: Fuzzy logic control configuration

Since the position transducer produces non-fuzzy measurements, these were fuzzified by fuzzification (mini-max composition rule). Similarly, since the servomotor cannot respond directly to the fuzzy controller output, the outputs were fuzzified bu defuzzification (centroid) rule as proposed by Lee[14].

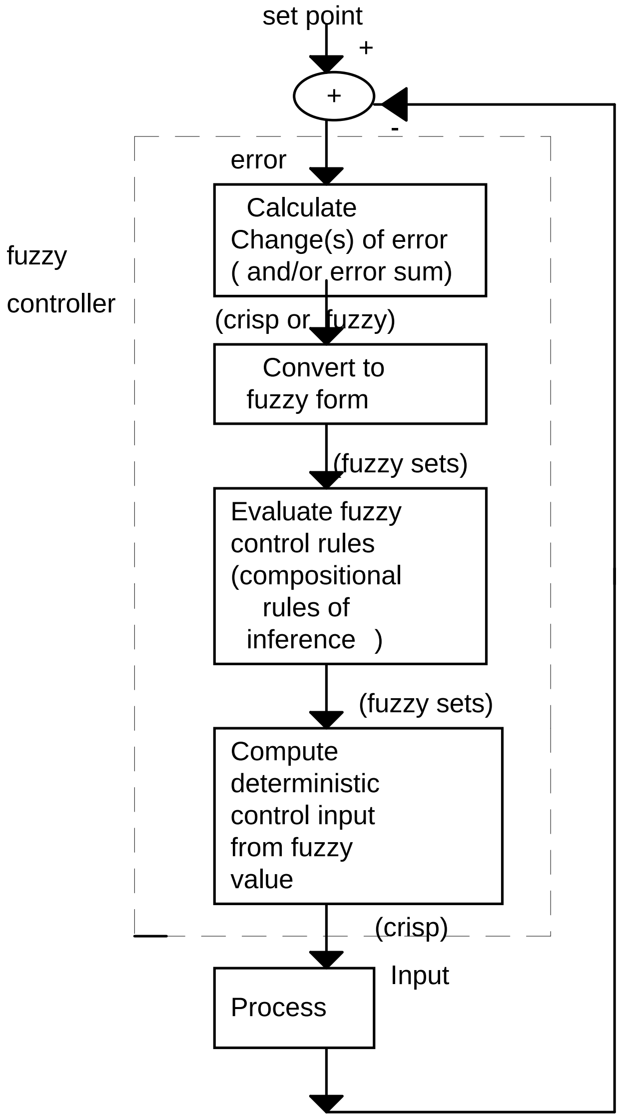

Figure 2 Fuzzy control system architecture

The knowledge base and rule base of the fuzzy logic controller consists of about 36 production rules. They are as shown in Table 1. The process error e(t) and the deviation in error δe(t), defined below, constitute condition variables of each rule

$$e(t) = r(t) - y(t)$$

$$\delta e(t) = [e(t)-e(t-1)] / T \qquad (1)$$

where r(t) is the set-point (reference) at time t, y(t) is the process output and T is the sampling period of the process computer. The conclusion of each rule refers to an incremental control output δu(t), defined as

$$\delta u(t) = [u(t) - u(t-1)] / T \qquad (2)$$

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The linguistic interpretation of each rule can be derived from table 1. For example, from the third column and the first row, the derived rule states: If the error is Small Negative (SNE) and the Error Deviation is Large Positive (Large Positive) then apply Medium Negative Control (MNC).

δe(t)→ e(t)↓	LNE	MNE	SNE	SPE	MPE	LPE
LPDE	LNC	LNC	MNC	SPC	MPC	LPC
MPDE	LNC	LNC	MNC	SPC	MPC	LPC
SPDE	LNC	MNC	SNC	SPC	MPC	LPC
SNDE	LNC	MNC	SNC	SPC	MPC	LPC
MNDE	LNC	MNC	SNC	MPC	LPC	LPC
LNDE	LNC	MNC	SNC	MPC	LPC	LPC

Table 1 Rule table for the fuzzy controlled process

To make the control strategy simple the rules and the membership functions are used as proposed by Batur et. al., in (15). The rules are written using a qualitative feel for a two-measurement (e,δe) and one-output(δu) controller configuration. They are intended to provide convergence to the set-point. They are also confirmed by an experimental operator response to the process outputs. The membership functions of a fuzzy logic controller define the linguistic variables. For each membership function following quantities need to be specified:

1. the shape of the membership function,
2. the universe of discourse,
3. whether the membership function will remain fixed or adjusted on line.

The transducers and actuators determine the practical range of discourse on variables e and δe and is generally limited to 4-20 mA or 0-10 V. The shape of the membership functions for e and δe are assumed to follow exponential functions of the following forms:

$$m(x) = \exp(-\beta_1 x^2) \quad ; \textit{for small linguistic quantities}$$
$$m(x) = 1 - \exp(-\beta_2 x^2); \textit{for large linguistic quantities} \quad (3)$$
$$m(x) = \exp[-\beta_3 (x - \Delta^2]; \textit{for medium linguistic quantities}$$

where the variables x denotes both e and δe and (Δ) is a scaling parameter. Figure 3 shows the membership functions associated with e and δe. It is also assumed that these membership functions will not change during the application of the fuzzy controller. For the controller output δu, the linguistic quantities are defined by linear but adjustable membership functions as given below:

$$m(\delta u) = (1/C_{\max})\delta u \quad \textit{for small, medium and large control actions with different } C_{\max} \textit{ values}$$

In each case the $C_{\max}$ value determines the slope of the membership curve as shown in figure 4. This simplified form is chosen to tune the controller by simply changing the $C_{\max}$
value. For example, changes in $C_{\max}$ can be related to those of the controller gain. For example, increasing $C_{\max}$ will increase the control output amplitude for a given linguistic variable and membership value. Therefore, controller gain can be adjusted by manipulating $C_{\max}$.

fuzzy
set↓ e(t)→

	-2	-1.32	-0.66	0	0.66	1.32	2
+L	0	0	0	0	0.2	0.5	1.0
+M	0	0	0	0.1	0.5	1.0	0.5
+S	0	0	0	0.5	1.0	0.5	0.2
0	0	0	0.2	1.0	0.2	0	0
-S	0.2	0.5	1.0	0.5	0	0	0
-M	0.5	1.0	0.5	0.1	0	0	0
-L	1.0	0.5	0.2	0	0	0	0

fuzzy
↓ set δe(t)→

	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5
+L	0	0	0	0	0	0	0	0	.2	.5	1	1
+M	0	0	0	0	0	0	.2	.5	1	1	.5	.2
+S	0	0	0	0	0	.2	.5	1	.5	.2	0	0
0	0	0	0	0	.1	.3	1	.3	.1	0	0	0
-S	0	0	0	.2	.5	1	.5	.2	0	0	0	0
-M	0	.2	.5	1	1	.5	.2	0	0	0	0	0
-L	1	1	1	.5	.2	0	0	0	0	0	0	0

Figure 3 Membership functions associated with error and change of error

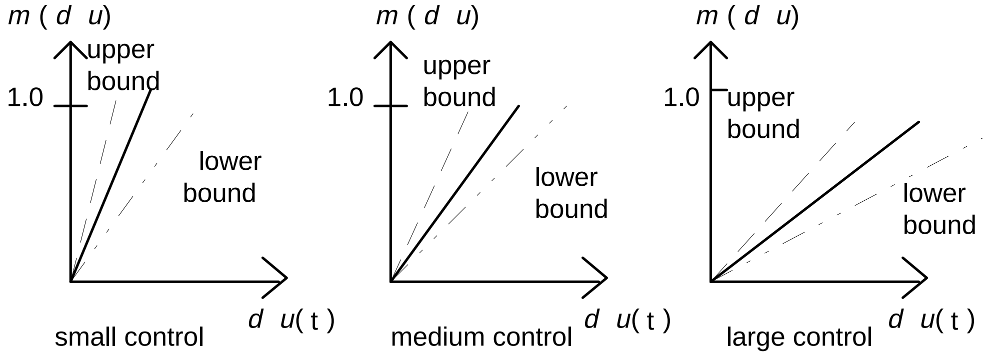

Figure 4 Membership functions associated with controller output

4. Tuning strategy for the controller

The selection of the proper combination of all controller gains settings is called tuning. The ultimate purpose of tuning is to make the resulting closed loop response as close as the desired design criteria. In general, tuning the controller to changing process and environment dynamics can be accomplished either by adjusting the membership functions, or by changing the finite set of values describing he universe of discourse and adjusting the set of rules in the knowledge base. We used the method of adjusting the membership function as reported by Batur et.al. in (15).The controller membership functions in the knowledge base are adjusted according to the tuning curve shown in Figure 5. This curve is one of the possible way to tune the controller to adapt to changing operating conditions. This can be quantitatively described as

$$C_{\max} = f_1\{e_{\max} \; or \; \hat{e}(t+1|t)\} \quad (4)$$

where, $e_{\max}$ *is the absolute* max*imum error observed within thepast observation window, and*, $e(t+1)t$ *is the predicted process output error*

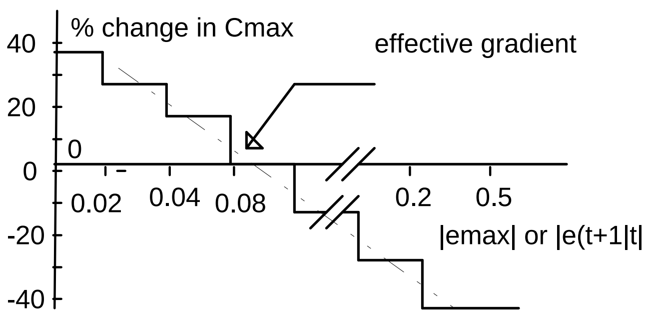

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Figure 5 Implemented changes in the controller member ship function as a function of measured or predicted error

In this method, increases in $e_{\max}$ or $\hat{e}(t+1|t)$ will decrease the membership function parameter $C_{\max}$. The relationship between $C_{\max}$ and increases in $e_{\max}$ or $\hat{e}(t+1|t)$ is organsed as a 2-D look-up table, by using refined Ziegler-Nichols approach as cross-reference as suggested by Hang et. al. in (16).
This tuning process effectively creates a 'cautious' controller avoiding oscillations following a process upset. However, by changing the effective gradient in Figure 5, the controller c an also be made sensitive. In this case, it responds with larger amplitudes following a predicted actual error.

5. Implementation and results

The comparison of the performance of the ZN-tuned PID controller and the proposed fuzzy tuned PID controller was simulated first followed by experimental verification. The experimental set up used is as shown in Figure 6. The The C cross-compiler for the 8031 based microcontroller allows fuzzy rules to be written, fuzzification, defuzzification and down loading to 8031 assembly language code to be done easily. However, the dedicated microcontrollers with fuzzy logic kernel like ST6(from SGS Thomson) will allow the development of fuzzy logic controller with much ease and much faster implementation.

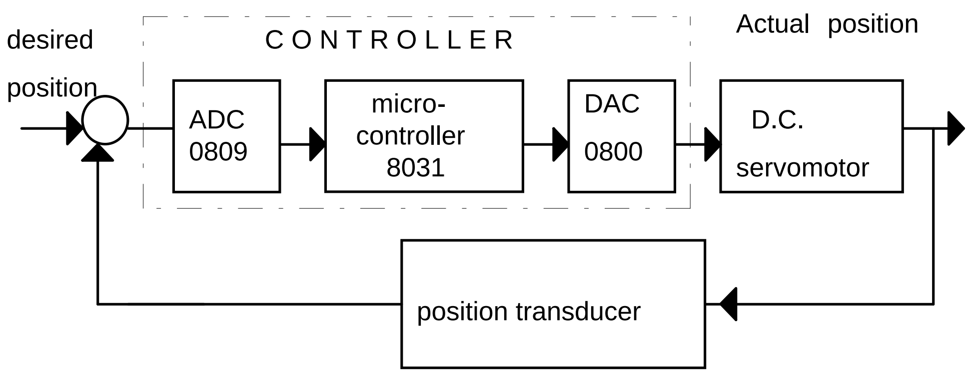

Figure 6 Hardware setup for experimental verification

The pulse transfer function of the zero-order hold, plant (dc servo motor) and sampler used for simulation is:

$$G(z)=\frac{0.3679z+0.2644}{z^2-1.368z+0.368}$$

The specifications were stated as minimum steady-state position error for step input, about 20 % overshoot, settling time of about 4 seconds and it should reach 1 % of its final value after 0.1 secs.The simulated and experimental responses comparing ZN-tuned controller and fuzzy tuned controller is shown in Figures 7 and 8.

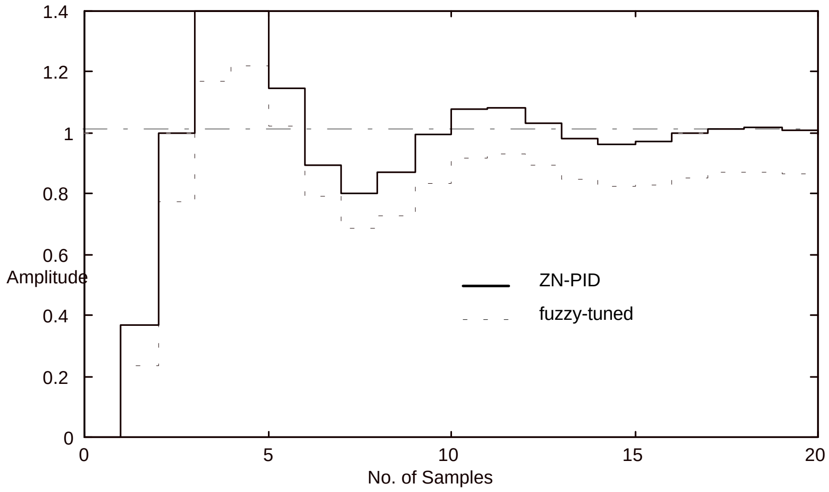

Figure 7 Simulated response comparing PID and fuzzy-tuned controller

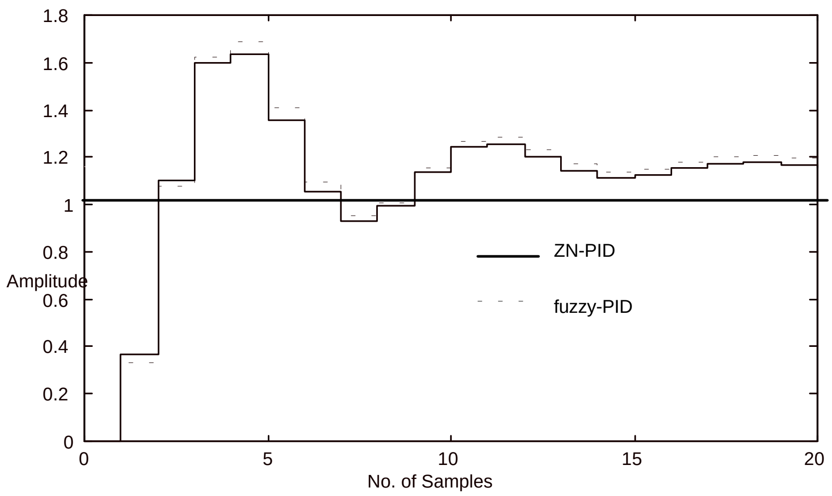

Figure 8 Experimental response of ZN-tuned and fuzzy tuned controller

6. Conclusions

A comparitive study of ZN-tuned and fuzzy logic tuned PID controller for a position control system was reported in the paper.The PID paremeters were chosen as Kc=3, Ti=25 and Td=6. The simulated and experimental responses shown in figures 7 and 8 show that performance of the fuzzy logic controller closely resembles that of ZN-tuned controller. The settling time and rise time of the two controllers met the design specifications.. However, percentage overshoot of the both the controller is not as desired as the sampling time could to be changed to a great extent. The sampling speed was limited by the ADC and DAC circuits. As one of the objective was ease and cost-effective implementation of fuzzy logic ideas in actual practice, it was not possible to achieve the performance of the fuzzy-tuned controller as desired. However, with the innovations in the cost-effective fuzzy logic hardware and detailed study of stability of fuzzy logic controllers it is possible to realize the performance of fuzzy logic controllers as desired. Also different fuzzification and defuzzication techniques can yield better performance. Although fuzzy controllers are designed and implemented in many industrial applications, their stability and robustness characteristics have not yet been fully analysed. One reason is that conventional methods are not directly applicable and should be either reformulated or modified. Since a fuzzy feedback control system is essentially non-linear, stability analysis has to be carried out using well known stability analysis of non-linear systems.

7. Index

Servo control, PID, fuzzy logic, Ziegler-Nichols

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