Afyon Kocatepe Üniversitesi FEN BİLİMLERİ DERGİSİ | 2 (2) 69- 84 | Afyon Kocatepe University JOURNAL OF SCIENCE

FUZZY CONTROL METHOD AND ITS' PROTOTYPE APPLICATION FOR PRODUCT PACKAGING AUTOMATION SYSTEMS

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ABSTRACT
In this paper, a new prototype design for product-box assembly automation systems is presented . A PLC is used to automate the system. Speed of the conveyor band that carries the products is controlled by a fuzzy controller. Fuzzification, fuzzy decision making and defuzzification procedures are realized by PLC ladder instructions. Fuzzy logic controllers can infer coherent results in uncertain conditions when it is necessary to control a complex system which has difficulties to model using mathematical ways. Application of fuzzy logic theory in control systems proved to be superior to the conventional control systems. Microprocessor based control systems, such as Programmable Logic Controllers, may form a suitable application area of fuzzy logic theory to solve these problems.

Key words: PLC's, Fuzzy Control, Automation

ÜRÜN PAKETLEME OTOMASYON SISTEMLERI İÇIN BULANIK DENETIM YÖNTEMI VE BUNUN İLK ÖRNEK UYGULAMASI

ÖZET

Bu çalışmada, ürün-paket birleştirmede kullanılan otomasyon sistemleri için yeni bir ilk örnek tasarımı sunulmuştur. Sistemin denetimi için PLC kullanılmaktadır. Ürünleri taşıyan band bir bulanık denetleyici tarafından denetlenmektedir. Bulanıklaştırma, bulanık karar verme ve durulaştırma yordamları PLC merdiven komutları ile gerçekleştirilmiştir. Bulanık denetleyiciler, karmaşık denetim sistemlerinde belirsiz durumlarda oldukça tutarlı sonuçlar alabilmektedir. PLC gibi mikroişlemci tabanlı denetim sistemleri, bu tür sorunların çözümünde bulanık mantık kuramı için uygun bir uygulama alanı oluşturabilirler.

Anahtar Kelimeler: PLC'ler, Bulanık Denetim, Otomasyon

1. INTRODUCTION

PLC is the most widespread area of micro-processor applications on industrial control. PLCs can easily process continuous signals such as speed and heat by means of analog input/output modules [1]. Speed data, that is acquired from encoder of a motor is counted by a High Speed Counter unit and is transferred to a memory area as a digital data. Then it is compared to the set value entered before [2]. Because it is unnecessary to model a dynamic driver system to design a Fuzzy Controller, and performance of fuzzy controller is insensitive to change of parameters, it is rather suitable for applications of motor driver systems [3].

Although, new control methods has been an active field of research over the last few years, rather seldom attention has been paid to the application of either fuzzy or neural networks on PLC's or on the other industrial controllers. Reference 4 attracts attention to applicability of fuzzy control on PLCs and investigates experimentally realization of this proposal by means of a special fuzzy logic unit which is carried out by a software that performs fuzzy logic processes. Reference 5 suggests an alternative method that eliminates the necessity of a special unit in fuzzy control. Its' subject is focused on fuzzification, fuzzy decision making and defuzzification procedures which are realized by PLC ladder instructions. In this study, principal suggestions of these preceding paper woks and their mathematical and software bases are discussed extensively. In addition, performance of the fuzzy controller is compared with a multi-level controller. And a program is prepared in Delphi 5.0 to acquire and to store the data obtained from the experiment mechanism. The program provides us facility in observing and in comparing the results of these control methods.

2. MATERIAL AND METHOD: CONTROL OF THE CONVEYOR SYSTEM

In this application, fuzzy control method is used to control two conveyors which are used for packaging products. Products are carried at irregular intervals but at a fixed speed on conveyor A. Boxes are carried at regular intervals on conveyor B, which processes parallel to conveyor A. Control program allows to synchronize the arriving time of products and boxes to assemble area by means of adjusting speed of Conveyor B. Required information are the distance between the product and the box, the derivative of the distance [6].

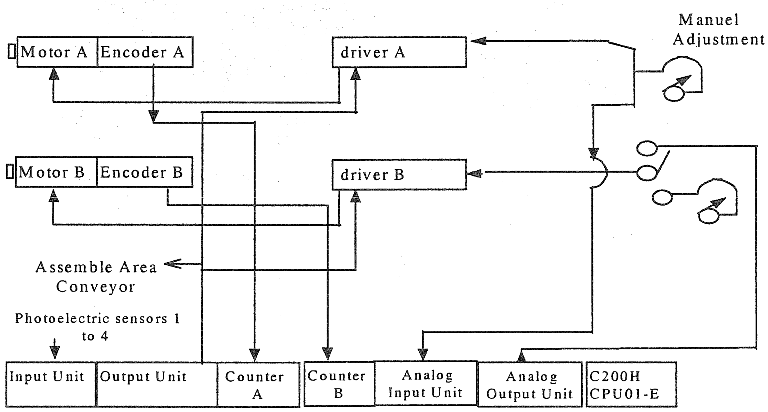

Figure 1. Control system of conveyors

2.1 The System's operating principle

The distance to the first photoelectric sensor (PH2) that the box is carried on the conveyor B is determined, before the product reaches to the first photoelectric sensor (PH1) on conveyor A. The distance can be calculated by the rotary encoders and High Speed Counters [7] mounted at the back of motors. The distance is called to be product/box offset. This offset determines the main fuzzy linguistic rules of the system. They are as follow:

"If the product/box offset is large, then slow down conveyor B."
"If the product/box offset is small, then don't change conveyor B's speed much "

Fuzzy logic processing runs under these rules and the rules related to the dervative of the product/box offset allows us very smooth adjustment of conveyor B's speed.

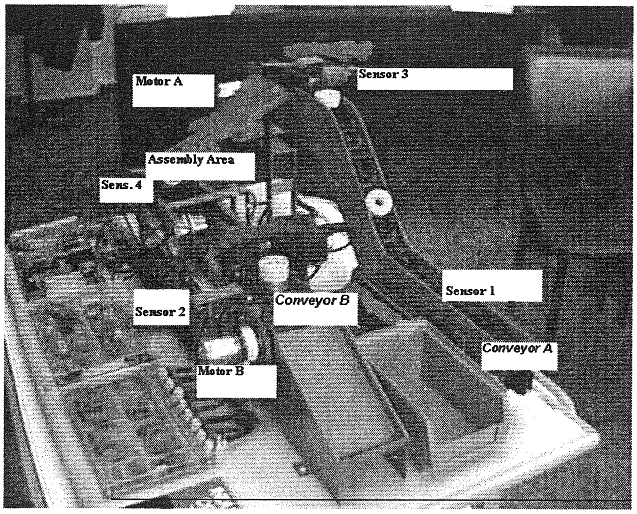

Figure 2. Industrial control trainer set

12.2.Forming the Knowledge Base

Input data of product/box offset is calculated by means of taking relative position of product to box, which may be called as Error, shown below [8].

E=(Rot. Enc. A value)-(Rot. Enc. B value) (1)

Input data for derivative of product/box offset (DE), is the difference between the last value of E, (E (t)) and the previous value of E, (E(t-1)):

$$\text{DE} = \frac{\Delta E}{\Delta t} = \frac{E(t) - E(t-1)}{\Delta t} \quad (2)$$

where sampling time $\Delta t = 1$ sec. Output data represents the motor speed which adjusts speed of conveyor B.

2.3. Forming the Fuzzy Rules

Rules are created by organizing our information and past experiences about a system, with expressions which is being used in daily life. In organizing these expressions a way may be followed such as below [5]:

Table 1. Organizing the rules

E	Box is ahead		About even	Product is ahead	
DE					
Box is faster	Slow box a lot	Slow box a lot	Slow box a little	Speed it up a little	Speed it up
	Slow box a lot	Slow box	Slow box a little	Speed it up a little	Speed it up
About even	Slow box	Slow box a little	Do not change	Speed it up a little	Speed it up
	Slow box	Slow box a little	Speed it up a little	Speed it up	Speed up a lot
Box is slower	Slow box	Slow box a little	Speed it up a little	Speed it up	Speed up a lot

So, input data, output data and expressions in the table above are converted to labels as shown below [11]:

Input Data:
Product/box Offset Error : E
Derivative of the Error: DE

Output Data:
Speed Adjustment Voltage of Conveyor B: VB

Expressions above can be converted to labels as shown in Table 2:

Table 2. Rule Base

E	**NB**	**NS**	**ZG**	**PS**	**PB**
DE					
PB	NB	NB	NS	PS	PM
PS	NB	NM	NS	PS	PM
ZG	NM	NS	ZG	PS	PM
NS	NM	NS	PS	PM	PB
NB	NM	NS	PS	PM	PB

Where the meaning of the symbols are;

NB: Negative Big, NM: Negative Medium, NS: Negative Small,
ZG: Zero Grade, PS: Positive Small, PM: Pos. Medium, PB: Pos. Big

3. FUZZY CONTROL OF THE SYSTEM BY MEANS OF BASIC PLC INSTUCTIONS

In this section, **sum-min** method is used for inference and **Center of Gravity** method is used for defuzzification. Max-min method is not preferred to avoid adding extra ladder rungs to calculate maximums of membership degrees. Fuzzy controller acquires data from the addresses which are assigned before for inputs, fuzzifies and infers by comparing with the prepeared rule base, then writes the fuzzified result to the address which is assigned for output. Forming of fuzzification, inference and defuzzification algorithms can be done by basic PLC instructions such as multipy, divide, add, subtract, min, compare, move etc [5].

3.1. Determination of Membership Functions and Ranges of the Error (E) Variable

Length of Conveyor A is 1800 tour. Length of Conveyor B is 450 tour but it is scaled to length of Conveyor A by means of multiplying the tour/s data with 4. Speed of Conveyor A is constant and approximately equal to 85.7 Hz. Speed of Conveyor B can be controlled between 11.5 Hz and 46 Hz (If the range is scaled according to Conveyor A, it is between 46 Hz and 184 Hz). In this situation, Conveyor B can run at a speed which is minimum 0,536 times and maximum 2.14 times of Conveyor A. Because of this, a new product settled on conveyor B could not catch the box on conveyor A, if the box passed half of the way, although conveyor B runs in maximum speed. Similarly, a box could not catch the product on conveyor B, if the product passed half of the way, although conveyor B waits in its minimum speed. So, Error (E) must be between -900 and +900. Conveyor A has to be stopped if error is more than +900 and Conveyor B has to be stopped if error is smaller than -900 tours. E is restricted between these values.

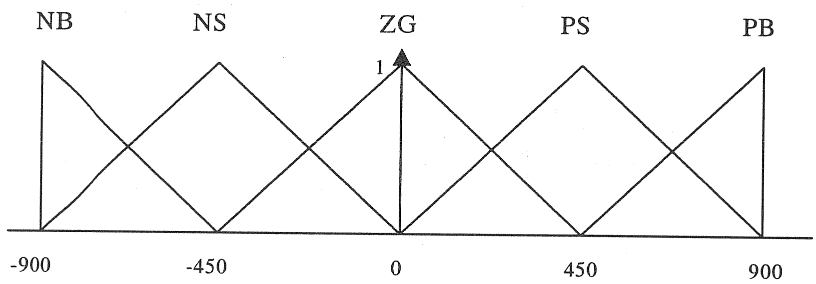

Figure 3. Calculation area of *Variable (E)*

Negative numbers can not be directly written in the PLC program. While E is found out, if the result of subtraction is negative, carry bit must be must be checked. And if it is active, the result must be resubtract from zero. Instead of that, summing of the range with 1000 will carry the range of E to positive area and this will facilitate the solution.

Transition points of membership functions which are at 100, 550, 1000, 1450 and 1900 are seperated because of avoiding to activate and calculate 9 rules instead of 4 rules in a certain time.

In the Fig.4, one side of an equilateral triangle is 450 unit. PLCs round the numbers between ($0 \leq x<1$) to 0. Because of this, choosing of membership degrees between ($0 \leq x<450$) would be more suitable. According to similarity of an equilateral triangle, calculation of a (y=x) membership functions degree would get easier [5].

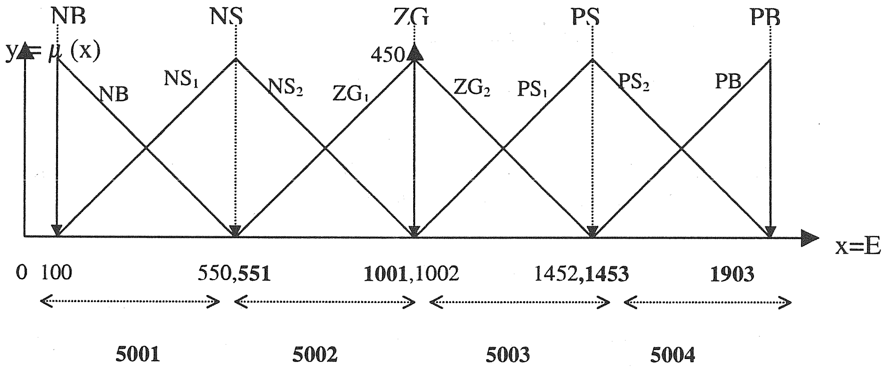

Figure 4. Function couples which will be calculated according to the interval in which current E exists

Membership functions NS, ZG and PS are formed by two linear equations, slopes of which have opposite signs.

Table 3. Functions which will be calculated according to the interval in which current E exists

Functions	Current Interval (x=E)	Bit which symbolize current Interval in program
y_1 = NB = 550-x y_2 = NS_1= x-100	100- 550 100-550	5001
y_3 = NS_2= 1001-x y_4=ZG_1 = x-551	551-1001 551-1001	5002
y_5=ZG_2 = 1452-x y_6= PS_1 = x-1002	1002-1452 1002-1452	5003
y_7= PS_2 = 1903-x y_8= PB = x-1453	1453-1903 1453-1903	5004

3.2. Determination of Membership Functions and Ranges of Derivative of the Error (DE) Variable

Observations show that Derivative of the Error changes between -12, +12 tour/s. Similarly, membership functions and ranges for DE are determined.

Table 4. Functions which will be calculated according to the interval in which current DE exists

Functions	Current Interval (x=DE)	Bit which symbolize current Interval in program
y_1 = NB = 16-x y_2 = NS_1= x-10	10-16 10-16	6001
y_3 = NS_2= 23 -x y_4=ZG_1 = x-17	17-23 17-23	6002
y_5=ZG_2 = 30 -x y_6= PS_1 = x-24	24-30 24-30	6003
y_7= PS_2 = 37-x y_8= PB = x-31	31-37 31-37	6004

3.3. Determination of Membership Functions and Ranges of Speed Adjustment Voltage of Conveyor B (VB) Variable

Control data is between 0 and 07FFH (BCD 0 and 2047) . Analog output of the PLC converts these data between 0 and 5V to drive Conveyor B driver. The driver provides a proportional voltage between 0 and 12V to the Conveyor motor [11]. The motor runs between 0 and 184 Hz speed limits. This area is divided into 7 singletone membership functions (Fig.5).

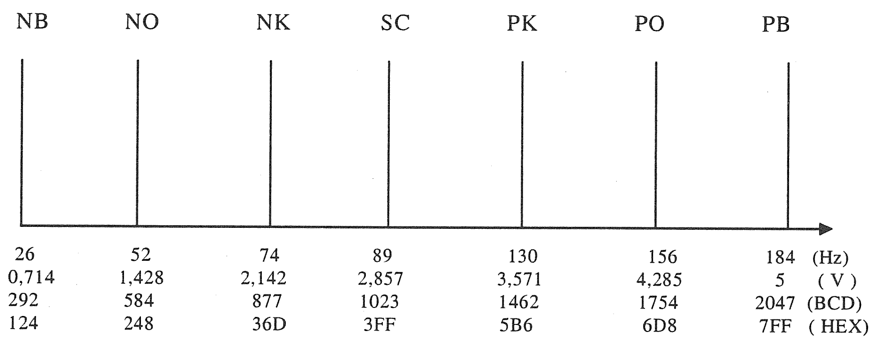

Figure 5. Calculation interval for the controller output variable

4. ANOTHER METHOD: MULTİ-LEVEL CONTROL OF THE CONVEYOR SYSTEM

A multi-level control program is prepared in order to compare performance of fuzzy controller [12]. The program is similar to the former, but crisp sets are used in stead of fuzzy sets. This method allows to use a similar rule base, provides us to consider effects of the fuzzification and deffuzification processes. Error and Derivative of Error Regions are divided into 5 intervals.

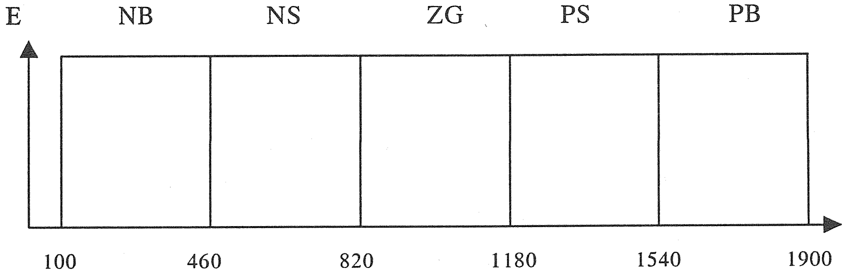

Figure 6. Crisp Sets of E Input Variable

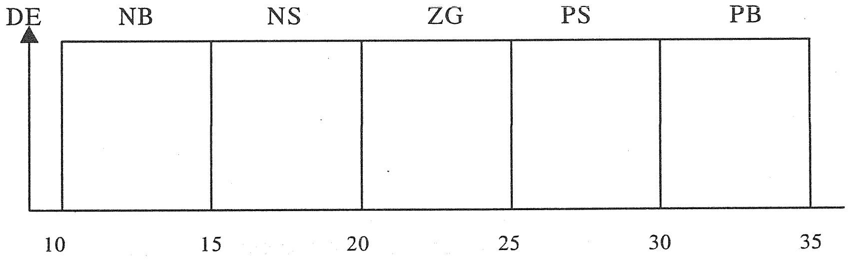

Figure 7. Crisp Sets of DE Input Variable

The sets of E are represented by internal relays. NB, NS, ZG, PS, PB are symbolized by 5000, 5001, 5002, 5003, 5004, respectively. In the same way, the sets of DE are represented by 6000, 6001, 6002, 6003, 6004. Controller produces 25 different output levels.

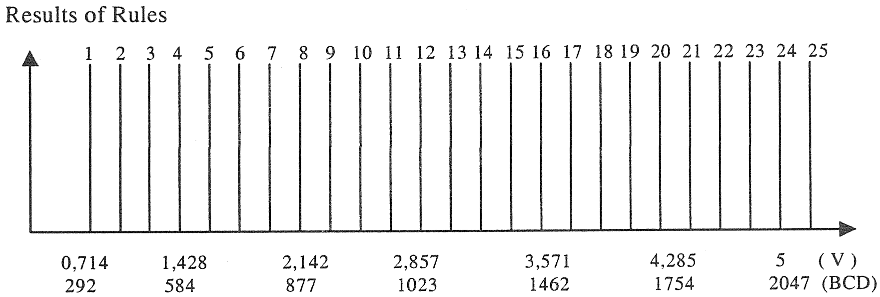

Figure 8. Control Output Levels

The controller may run at 25 different speeds according to the different conditions appeared by the result of the rules.

5. EXPERIMENTAL RESULTS

5.1. Results of Fuzzy Control

Error changes versus time is examined. In this purpose, error may be measured and stored in a sequence in 20 different DM areas at 1 second period intervals by the PLC program [4]. But, the data obtained from the encoders are preferred to acquire and to store in computer environment by an I/O card, independent of PLC. Thus the error changes are provided to be observed online. Max. control process time for the system is about 20 sec.

Maximum overshoot is calculated according to the Equation 3.

$$MO = y_{ss} - y_{ext} \quad (3)$$

y_{ext} is the extreme value and y_{ss} is the steady state value (= 0) of the error [13]. y_{ext} is the greatest absolute value of the negative or positive values of the Error after the first pass of y_{ss}. Delay time (t_d) is calculated due to % 50 of the time passed between initial error value and steady state error value. Rise time (t_r) is the time which error value passed between %90 and % 10 of maximum error value (steady state value=0) . Settling time is a time, passes until error reaches to %5 of max. error value and never exceeds this band.

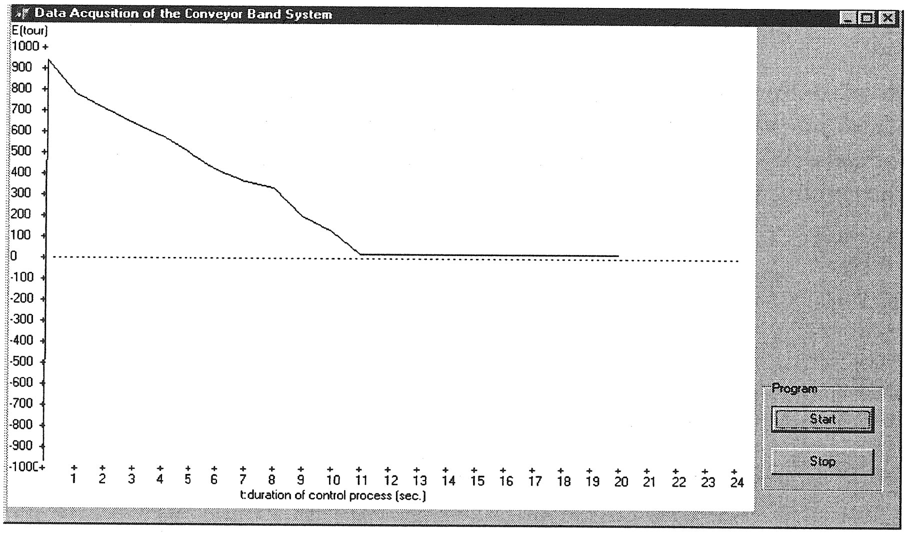

Figure 9. Error Change versus Time for a Positive Big Value (Fuzzy Control)

If a product is highly ahead from a box, a positive big error will be occurred (Fig.9). In this experiment, Error is rapidly getting closer to zero. MO=0, t_d= 6 sec. , t_r=10 sec., t_s= 11 sec.

5.2. Results of Multi-level Control

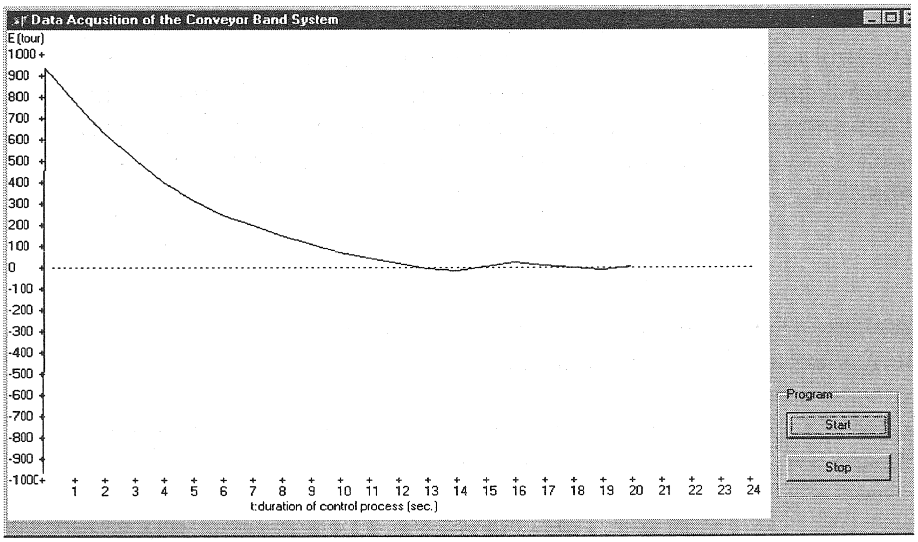

Figure 10. Error Change versus Time for a Positive Big Value (M.- L. Control)

The controller was initialized in the same starting situations. Response of the controller for a positive big error value is shown in Fig.10. In this experiment, MO=23, t_d= 3,5 sec. , t_r=9 sec., t_s= 11 sec.

6. CONCLUSIONS

Axle which rotates the conveyor band is not ideal. The reasons of the ripples are increasing of frictions and compressions in certain positions of the band in a period .

Error indicates a smooth decrease in the multi-level control. Its' delay time and rise time is shorter than the fuzzy controllers' results. And the fuzzy controller could not remove a small steady state error. But its' results are ripple free and no overshoot has occured. Both control results have equal settling time. In the future works fuzzy rules, number and locations of the membership functions may be changed to optimize the delay time, the rise time and the steady state error. A neurofuzzy controller may be used to optimize locations and forms of membership functions.

PLCs are industrial control systems and they have an important role especially for medium and large scaled processes. Nowadays fuzzy logic theory in control applications is on the point of popular control methods and industry has common expectations from the new control methods. In this study, control concepts of fuzzy logic theory is tried to put in practice on a redesigned industrial control trainer set which is used for PLC applications. Its performance is compared with another method. Combinations of fuzzy logic control and conventional control approaches may prove the best solutions.

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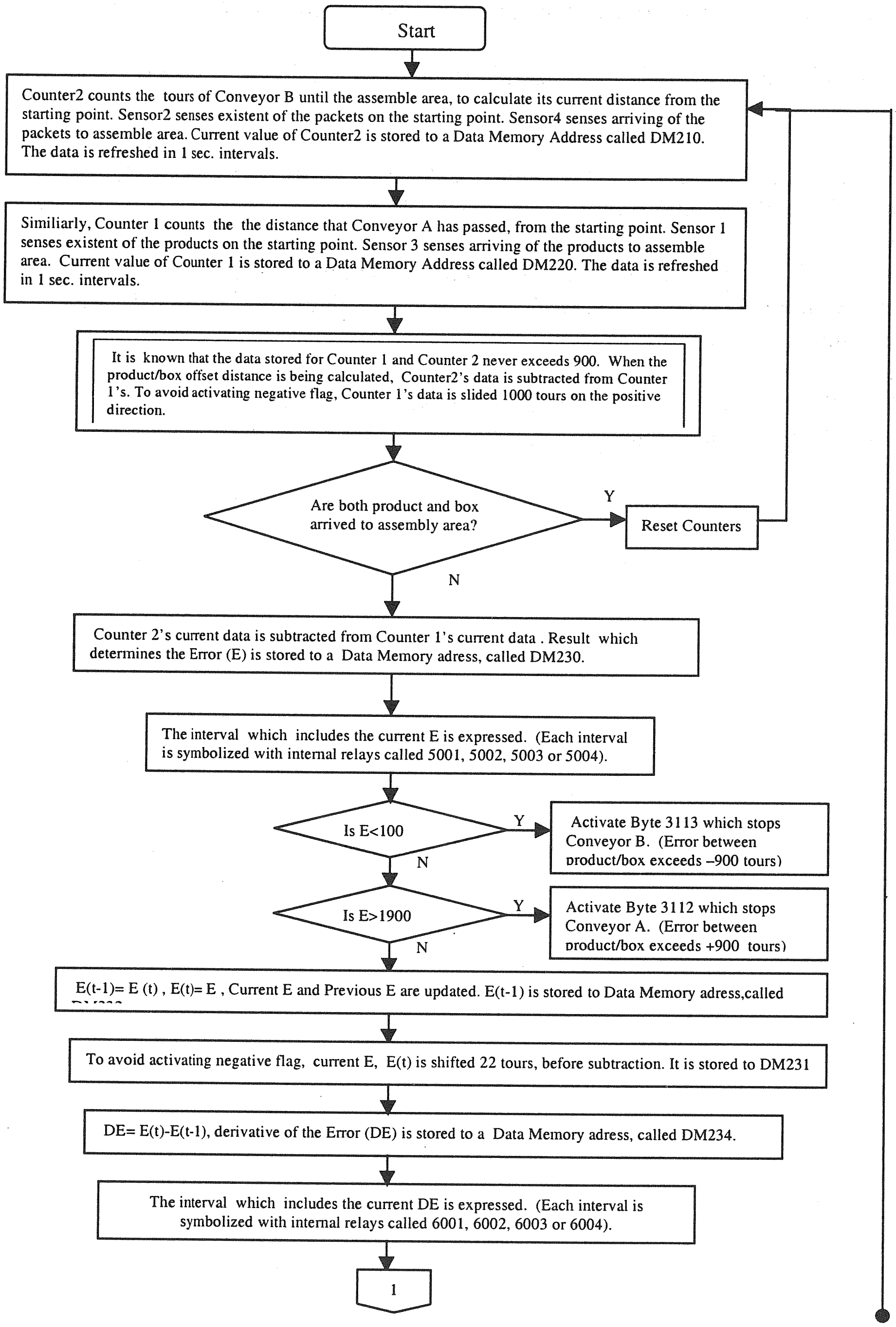
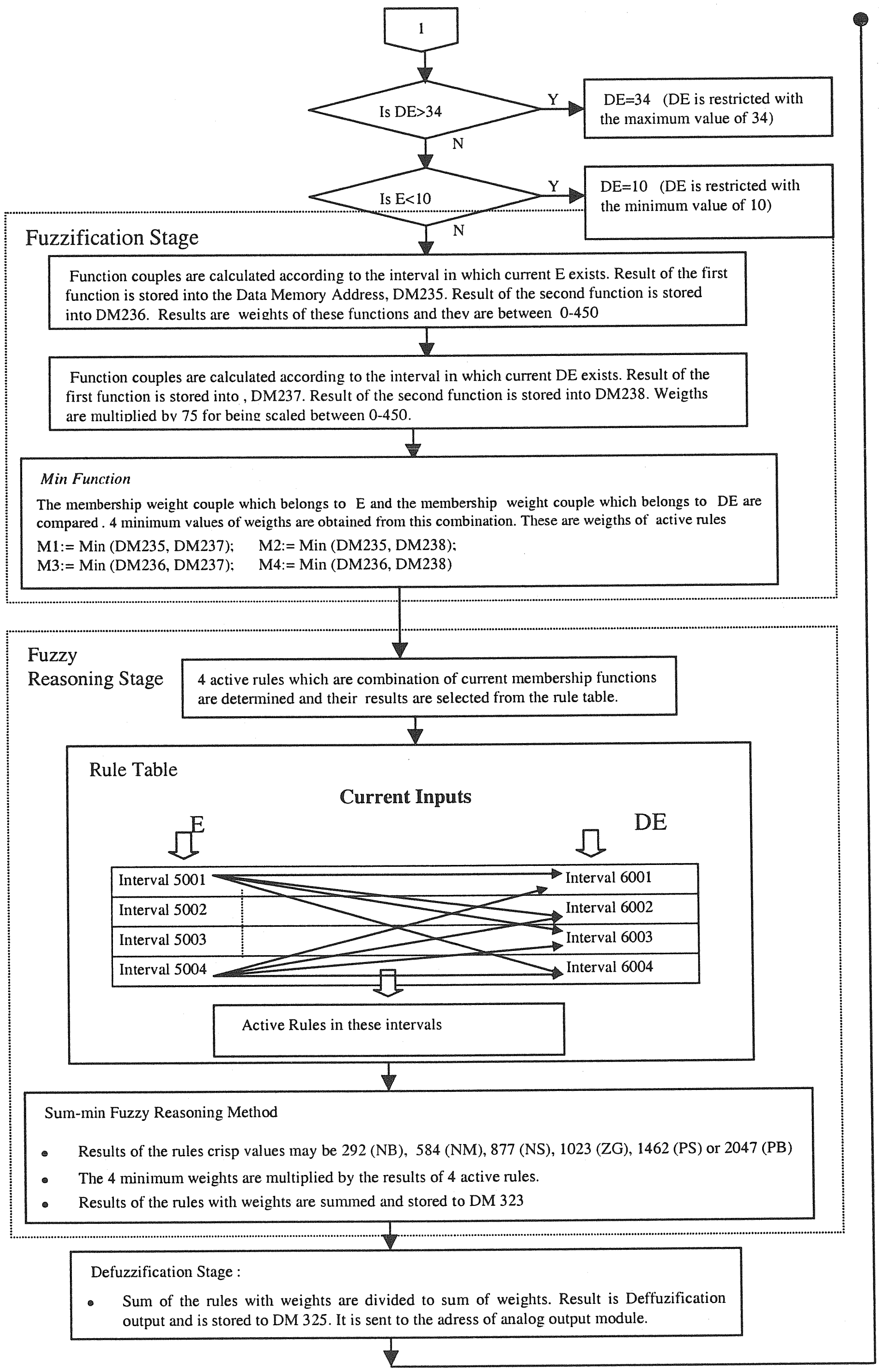
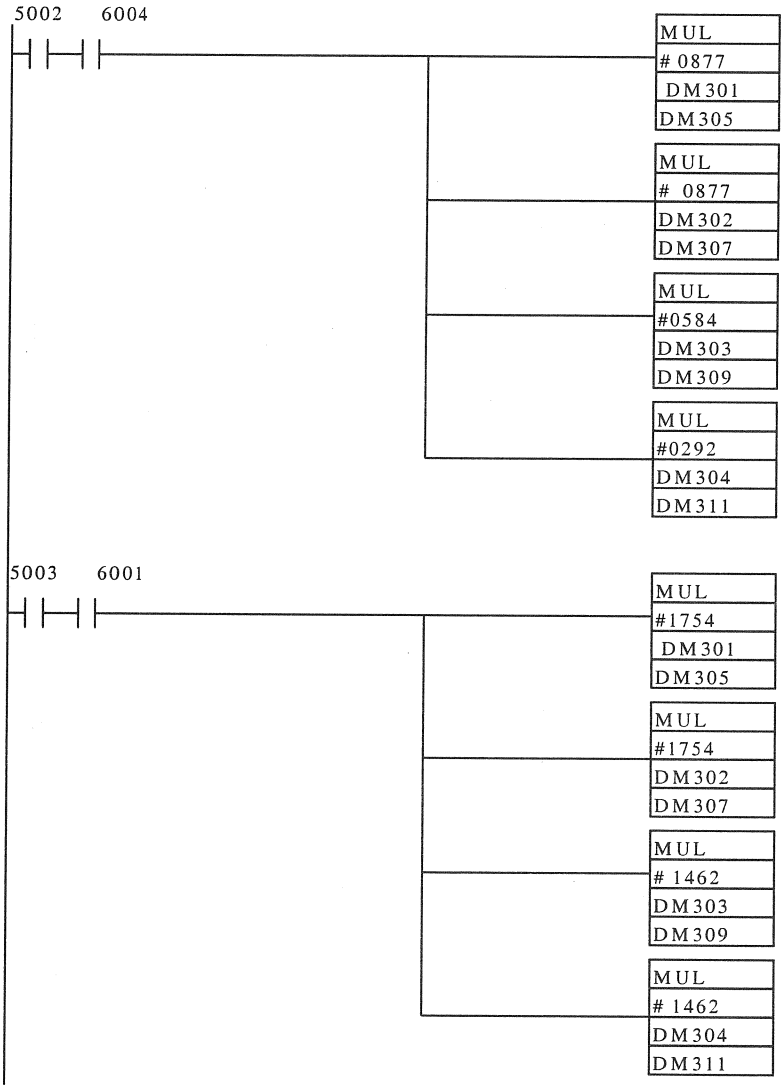
Appendix-A . Flowchart of the fuzzy control ladder program




1
Is DE>34
Y
N
DE=34 (DE is restricted with the maximum value of 34)
Is E<10
Y
N
DE=10 (DE is restricted with the minimum value of 10)
Fuzzification Stage
Function couples are calculated according to the interval in which current E exists. Result of the first function is stored into the Data Memory Address, DM235. Result of the second function is stored into DM236. Results are weights of these functions and they are between 0-450
Function couples are calculated according to the interval in which current DE exists. Result of the first function is stored into , DM237. Result of the second function is stored into DM238. Weigths are multiplied by 75 for being scaled between 0-450.
Min Function
The membership weight couple which belongs to E and the membership weight couple which belongs to DE are compared . 4 minimum values of weigths are obtained from this combination. These are weigths of active rules
M1:= Min (DM235, DM237); M2:= Min (DM235, DM238);
M3:= Min (DM236, DM237); M4:= Min (DM236, DM238)
Fuzzy Reasoning Stage
4 active rules which are combination of current membership functions are determined and their results are selected from the rule table.
Rule Table
Current Inputs
E
DE
Interval 5001
Interval 5002
Interval 5003
Interval 5004
Interval 6001
Interval 6002
Interval 6003
Interval 6004
Active Rules in these intervals
Sum-min Fuzzy Reasoning Method
Results of the rules crisp values may be 292 (NB), 584 (NM), 877 (NS), 1023 (ZG), 1462 (PS) or 2047 (PB)
The 4 minimum weights are multiplied by the results of 4 active rules.
Results of the rules with weights are summed and stored to DM 323
Defuzzification Stage :
Sum of the rules with weights are divided to sum of weights. Result is Deffuzification output and is stored to DM 325. It is sent to the adress of analog output module.

Appendix-B . Example ladder rungs



The 4 minimum weights are multiplied by the results of 4 active rules in fuzzy reasoning stage. First example rung activates the rules 7,6,12 and 11.

Rule7: If E is NS(in interval 5002) **AND** DE is PS(in 6004) then VB is NM (crisp value=584)
Rule6: If E is NS (in 5002) **AND** DE is PB (in 6004) then VB is NB (=292)
Rule12: If E is ZG (in 5002) **AND** DE is PS (in 6004) then VB is NS (=877)
Rule11: If E is ZG (in 5002) **AND** DE is PB (in 6004) then VB is NS (=877)

YAYIN KURALLLARI

1. Dergi "Hakemli Dergi" statüsüne uygun olarak yayınlanmaktadır.

2. Dergide yayınlanacak yazılar, Fen ve Mühendislik Bilimleri alanındaki konuları kapsar.

3. Gönderilen çalışmalar, alanında bir boşluğu dolduracak araştırmaya dayalı özgün çalışma veya daha önce yayınlanmış bir yazıyı değerlendiren, bu konuda yeni ve dikkate değer görüşleri ortaya koyan araştırma veya inceleme olmalıdır.

4. Yayınlanmak üzere gönderilen yazılar, özet dahil 15 sayfayı geçmemeli ve daha önce yayınlanmamış olmalıdır.

5. Dergi Yayın Kurulu, biçim açısından uygun bulduğu yazıları seçilmiş hakemlere (üç hakeme) gönderir, makaleler üç hakemin en az ikisinin oluruyla yayın alır. Yayınlanması için düzeltilmesine karar verilen yazıların yazarları tarafından en geç (posta süresi dahil) 10 gün içerisinde teslim edilmesi gereklidir. Bu süreyi aşan yazılar daha sonraki sayılarda değerlendirilecektir.

6. Dergide yayınlanan yazıların, telif hakkı dergiye aittir. Fen Bilimleri Dergisi telif hakkı karşılığında yazarlarına bir adet dergi ve 1. yazara 1 adet dergi ve 20 adet ayrı baskı gönderilecektir.

7. Yazım dili Türkçe ve İngilizce'dir. Makalenin başında Türkçe ve İngilizce olmak üzere en az 100, en fazla 200 kelimeden oluşan özet ile Türkçe ve İngilizce anahtar sözcükler (en az 3 en fazla 5 kelime) verilmelidir.

8. Hazırlanan yazı şu bölümlerden oluşmalıdır :Başlık, Yazarlar, Adres, Özet, Anahtar Kelimeler, İngilizce Başlık, Abstract, Key words, Giriş, Materyal ve Yöntem, Bulgular, Tartışma ve Sonuç, Kaynaklar. Türkçe hazırlanan yazıda Abstract'tan önce İngilizce başlık; İngilizce yazıda ise özetten önce Türkçe başlık bulunmalıdır. Yazarların unvanı yazılmamalıdır.

9. Dergiye gönderilen yazılar dört nüsha (yazar isimleri bulunan bir ve yazar isimleri bulunmayan üç nüsha) olmalı ve iki adet A4 zarfına 2'şer milyon TL'lik pul yapıştırılarak eklenmelidir. Ayrıca WINDOWS ortamında ve MS WORD 7.0 ve daha sonraki sürümlerinde yazılmalıdır. Yazı içinde kullanılan grafikler WINDOWS ortamında açılabilecek bir grafik formatında, fotoğraflar scannerda 300 dpi çözünürlüğünde taranmış olarak JPG veya GIF formatında gönderilmelidir. Dergiye gönderilen yazı, şekil ve fotoğrafların dijital kayıtları bir disketle gönderilmelidir. Şekil ve tablolar numaralandırılmalıdır. Şekil adı, şekil altında; tablo adı tablonun üzerinde yer almalıdır.

10. Yazı karakteri Times New Roman, 11 punto, satırlar tek aralıklı yazılacaktır.

11. Paragraflar satır başından başlamalı, iki paragraf arasında bir satır boşluk bırakılmalıdır.

12. Sayfa düzeni normal, sayfa yapısı üstten 5 cm, alttan 5.5 cm, soldan 4.5 cm, sağdan 4.5 cm, cilt payı 0 olmalı, herhangi bir özel format bulunmamalıdır.

13. Başlıklar ardışık olarak numaralanmalı ve satır başından başlamalıdır. Ana başlıklar büyük harflerle ve koyu, alt başlıklarda her kelimenin ilk harfi büyük ve başlık koyu olmalıdır.

14. Makalelerde dipnot kullanılmayacaktır.

15. Kaynaklar metin içinde ilk verilenden başlanarak numaralandırılmalı ve köşeli parantez içinde verilmelidir. Metin sonunda "kaynaklar" başlığı altında numara sırasına göre listelenmelidir. Listede kaynaklar aşağıdaki şekilde belirtilmelidir:

- Periyodikler: Yazar soyadı, Adının ilk harfi, (varsa diğer yazarlar aynı şekilde), Makale adı, Dergi adı, Cilt no (sayı), Sayfa aralığı, (yayın yılı).
- Kitaplar: Yazar soyadı, Adının ilk harfi (varsa diğer yazarlar aynı şekilde), Kitap adı, varsa editörün adı, Basım sayısı, Cilt no, Yayınevi adı, Basıldığı yer, Sayfa sayısı, (Yayın yılı)
- Tezler: Yazar soyadı, Adının ilk harfi, Tez adı, Tez türü, Çalışmanın yapıldığı enstitü adı ve adresi, Sayfa sayısı, Çalışmanın yapıldığı yıl.
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Kaynaklar kısmı için örnekler aşağıda verilmiştir.

- Konuk M., Brown E., Biosynthesis of Nebularine Involves Enzymic Release of Hdroxylamine From Adenosine, Phytochemistry, 38:(1), 61-71, (1995).
- Konuk M., Babaoğlu M., Bitki Biyoteknolojisi II, Editörler; Özcan S., Gürel E., Babaoğlu M., 1. Basım, Vol:2, Selçuk Üniversitesi Basım Evi, Konya, 1-45sf (2001).
- Konuk M., Studies of The Biosynthesis and Properties of Nebularine, Doktora Tezi, Department of Biochemistry, University College of Swansea, 200, (1993)

16. Sayfa numarası çıktı üzerinde sağ üst köşeye verilmelidir.

17. Dergideki yazıların bilimsel ve idari sorumluluğu yazarına aittir.

18. Yazılar "Afyon Kocatepe Üniversitesi, Fen Bilimleri Dergisi, Fen-Edebiyat Fakültesi, ANS Kampüsü, AFYON" adresine gönderilecektir. Yazılara yazışma yapılacak yazarla ilgili ayrı bir sayfada ad, soyad, unvan, posta, telefon, faks ve e-posta bilgileri eklenmelidir.