Comparison of Conventional and Adaptive PID Controller for pH control in neutralization process

**Abstract**

This paper considers pH controller using Adaptive PID and conventional PID controller. Conventional PID parameters are calculated by Ziegler-Nichols (Z-N) closed loop and Cohen-Coon (C-C)open loop tuning methods. That problem proposed Adaptive PID how to tune PID parameters. Adaptive PID parameters are estimated by RLS method. Two control systems were compared experimentally and theoretically. The computational simulation results show the Adaptive controller has better performance than Conventional PID.

1. **Introduction**

A pH controller is a most important system in an wastewater treatment. Many methods for pH controller was proposed by many researchers [2], [3], [4]. One of the conventional controller is PID controller [5]. PID is the most industry controller which has three parameters ( proportional gain (Kp), integration gain (Ki), and derivative gain(Kd)). These PID parameters are determined by tuning methods based on closed loop or open loop response principles or by trial and error [6]. Many researchers are studied about how to tune PID parameters [6], [7], [8].

In this research, tuning method of PID parameters use recursive least square method (RLS). The proposed adaptive PID was applied on pH control system [7]. Adaptive PID using Recursive Least Square (RLS) method is suitable for linear and nonlinear systems.

1. **Mathematical Model of Neutralization System**

**2. MATHEMATICAL MODELING OF A NEUTRALIZATION PROCESS**

There are a lot of literature about pH model but the most widely accepted is McAvoy model for pH neutralization. Neutralization reaction of hydrochloric acid with sodium hydroxide that take place is the following

Product of the neutralization process is water and salt.

The main idea for pH modelling is to calculate and then transform to hydrogen ions and after that from to pH. is the difference between molar concentration of hydrogen ions and hydroxide ions . Due to fact that the used chemicals are strong base and strong acid they are considered as completely dissociated.

The solution should remain electrical neutral. So, electro neutrality equation is

(12)

Re-arranging the Eq.12, is

(13)

The *H+* balance equation and the OH- balance equation are used in order to calculate .

For the system equations are formed as:

*H+* balance equation is

(14)

*OH-* balance equation is

(15)

where

: volume of the solution

: flow of the acid

: flow of the base

Subtracting equations Eq.14 from Eq.15 and using Eq.13, a balance equation for is obtained

(16)

For simplicity equation 16 can be written as

(17)

Where is molar concentration of hydroxide ions and is molar concentration of hydrogen ions. There are measured at units of moles per liter.

The last term on the right-hand site of the equation 17 is nonlinear. So, this equation needs to be linearized. The method of the linearization around operating point is chosen. The operating point is 7 or due to the fact that the task is to neutralize the solution. Also Fa is known because the characteristics of the disturbance are known. The choice of the OP should be close to the steady state point. Now linearization can be proceed

Where is the operating point steady state value and is the difference from operating point (deviation). Also due to the fact that at steady state

(18)

Replacing these relationship in Eq.17

The part of this equation

and

So the linearized equation is

(19)

The related measurement that is available at the system is pH. So, a relationship between and should be defined.

Dividing Eq.19 by V the state space equation are obtained

and (20)

The system formulated as

(21)

(22)

Where

(23)

To convert space-space equations to transfer function

(24)

(25)

If we rearrange equation Eq.20

(26)

Put Eq.26 in Eq.25

(27)

So,

(28)

According to above equations, for our pH neutralization system,

(29)

The related measurement that is available at the system is pH. So a relationship between X and pH should be defined.

Using equation Eq.13

(30)

is also related to with

(31)

Where is the self-ionization constant of the water and it is equal with

Replacing equation Eq.18 and Eq.19

(32)

Solving this second order polynomial two solutions are obtained. Discarding the unrealistic one the relationship between and obtained

1. **Design of Adaptive PID controller for pH control Least Square Method)**
   1. ***Adaptive PID Control***

Adaptive PID RSM için kullanılan bu yöntemde, bir normalizasyon fonksiyonu aracılığı ile normalize edilmiş hata değeri elde edilir. Hata-Normalize fonksiyonu (g)

,

Kurallarını sağlayacak şekilde düzenlenmiş sigmaoid bir fonksiyondur.

Hata-Normalize fonksiyon adayları;

………………………………………………………………………………………………………………..….(1)

…………………………………………………………………………………………………………….(2)

…………………………………………………………………………………………………………….……(3)

…………………………………………………………………………………………………….…………(4)

ve değerleri, denklemlerden anlaşılacağı üzere, sırasıyla hata-normalize fonksiyonun değişim hızını ve normalize edilmiş hatanın maksimum ve minimum değerlerini temsil etmektedir.

Sonuçlar bölümünde bu değerlerin etkileri paylaşılacaktır.

…………………………………………………….……………(5)

: Normalize Hata

: Zamanla güncellenen PID parametreleri

İntegral Anti Wind-up

: alt sınır

: üst sınır

6 numaralı denklemi aşağıdaki şekilde yazacak olursak;

değerini güncellemek için adaptive control yasası düzenlemek adına geriye dönük performans değişkeni tanımlanır

= 1 ya da -1

Geriye dönük maliyet fonksiyonu

regülasyonu sağlayan pozitif tanımlı matris

Maliyet fonksiyonuna yinelemeli en küçük kareler minimizasyonu kuralı uygulandığında

denklemleri elde edilir.

* 1. **Conventional Clasic PID Control**

A proportional integral derivative (PID) control is a most common control loop feedback mechanism widely used in industrial control applications. It has good clarity and it is easy to implement. A PID controller helps to bring down the difference between the process variable and the set point by outputting the response with the desired value [1]. PID controllers are composed of three parts and principal control effects. The proportional (P) action gives a change in the input (manipulated variable) directly proportional to the error signal. The integral (I) action gives a change in the input proportional to the integral of error, and its main purpose is to eliminate offset. The less commonly used derivative (D) action is used in some cases to speed up the response or to stabilize the system and it gives a change in the input proportional to the derivative of the error signal. The overall controller output is the sum of the contributions from these three terms. The general form of the PID controller is given below in equation (1-3) [7].

 Proportional (P) part (1)

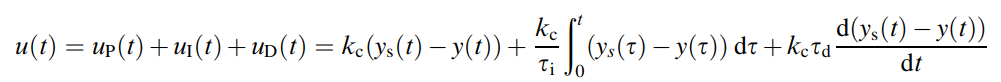
A picture containing text, watch, clock, gauge

Description automatically generated Integral (I) Part (2)

A picture containing text

Description automatically generated Derivative (D) Part (3)

The output of the PID controller is the sum of the above-mentioned three parts:

 (4)

where and denote the setpoint (the desired process output), the process output and the control output of the PID controller, respectively. The constants and are called the ‘proportional gain’, the ‘integral time’ and the ‘derivative time’, respectively.

As shown in (4), the PID controller is just a simple function of which the input is and the output is . It has excellent control performance and robustness. The PID controller has the three tuning parameters and , which should be set appropriately with in-depth consideration of the process dynamics [7].

The setpoint and the parameters and are set by the user. The process output *y* is measured. Then, it is straightforward to calculate the output of the PID controller. The outputs of the integral part and the derivative part are usually calculated by the numerical integration method and the numerical derivative method respectively.

The input and the output of the PID controller are and respectively. Then, the transfer function is

**Letter

Description automatically generated with medium confidence** (5)

Three steps are used to implement the algorithm of the PID controller in computers.

1. It is read the process output from the sensor.

2. It is calculated the control output of the PID controller.

3. It is sent out the control output to the actuator.

In the second step, the integral part and the derivative part can be calculated by a numerical integration method and a numerical derivative method respectively. The Euler method and the backward difference method are used for the integral part and the derivative part respectively [7].

PID control Algorithm is given below:

1. It is read the present ( sampling) process output from the sensor.

2. It is calculated the controller output on the basis of the present and one-step-before data.

proportional part (6)

integral part (7)

derivative part (8)

control output (9)

**3.** Send the controller output to the actuator. When the time passes as much as the sampling time Δ, repeat from step 1 with the k+1*-th* sampling.

1. **MATERIAL METHOD**

Neutralization reaction is the process in which an acid reacts with a base to produce salt and water. In this reaction, both the acid and base loose their properties to produce a new substance which is neutral in nature, the salt formed will neither be acidic nor basic. The preparation of sodium chloride involves the neutralization reaction between hydrochloric acid and sodium hydroxide. The acid and base react to produce sodium chloride (salt), water. The reaction is represented by the following equation: HCl + NaOH → NaCl+ H2O

Diagram

Description automatically generated

The communication between the sensor, the pump and the computer is provided by serial communication over the RS232 port on the computer. The communication between Matlab and the COM Port on the computer is carried out with matlab functions. Digital to Analog Converter is used to send a signal from the computer to the pumps, and Analog to Digital Converter is used to detect the Sensor data by the computer. Since ADC and DAC devices use the RS485 protocol, a RS232 to RS484 converter is used. The flow chart for the described processes is given in Figure1.

The pH neutralization system consists of two liquid streams acid and base, one feeding the acidic substance and the other feeds the base liquid. A special peristaltic pump at the rate of 40 ml/min is used to send acid to the vessel. The added Acid/base is mixed well using a mechanic stirrer that will be rotated at a speed of 300 rpm. Special type of pH probe is used to measure the pH inside the setup. In this experiment, strong acid (HCl) of 0.0091 molarity and strong base (NaOH) of 0.0227 molarity is prepared and used to conduct real-time experiments.

In this study, the pH neutralization process is modelled as a First Order Plus Delay Time model which is developed using state space equations. A comparative study of four different tuning methods for PID controllers using MATLAB, SIMULINK.

Mostly every system will have many objectives to be achieved. For designing a controller by satisfying all the requirements, algorithms are needed so as to tackle the problems that may arise. The conventional tuning methods which works based on fixed parameters will result in lesser performance when system necessitates controller. By using the above specified tuning methods can be determined the Proportional constant (C), Integral constant (I) and Derivative constant (D). This paper also includes Minimum Error Integral Criteria (ITAE, ISE and IAE) for determining the control performance. The time domain specifications and the performance index of different PID controllers were compared.

The simulation were done using MATLAB and SIMULINK. The pH neutralization PID control has been created in SIMULINK as shown in Figure 5 using the required blocks from the Simulink Library in MATLAB. (The step block parameters ; Step time = 0.5, initial value = 7, final value = 5,7 and 9)

**5.RESULTS**

Diagram

Description automatically generated

MATLAB Simulasyon Figur

Simulasyon Sonuçları

Mu = 0.5 v = 0.02

P = 1000\*I;

Diagram

Description automatically generated

P = 100\*I

Diagram

Description automatically generated

P = 10\*I

Chart, line chart

Description automatically generated

P = 100\*I V = 0.02

mu=0.1;

Chart

Description automatically generated

Mu = 0.5

Diagram

Description automatically generated

Mu = 1;

Diagram

Description automatically generated

Mu = 0.5 P = 100\*I

V = 0.01;

Chart, diagram

Description automatically generated

V = 0.02;

Diagram

Description automatically generated

V = 0.05;

Diagram

Description automatically generated

(Buraya 7.5-8.5-7.5 Deney parametreleri ile simulasyonlar gelecek?)

Experimental Results

In order to examine the effects of mu,v,P and k values, different experiments were carried out by keeping three of the values constant and changing one.

1.Effect of mu

Chart, line chart, histogram

Description automatically generated

Chart, line chart, histogram

Description automatically generated

Chart, line chart, histogram

Description automatically generated

2. Effect of v

Chart, line chart, histogram

Description automatically generated

Chart, line chart

Description automatically generated

Chart, line chart, histogram

Description automatically generated

3. Effect of P

Chart, line chart, histogram

Description automatically generated

Chart, line chart, histogram

Description automatically generated

Chart, line chart, histogram

Description automatically generated

4. Effect of k

Chart, line chart, histogram

Description automatically generated

Chart, line chart

Description automatically generated

Chart, histogram

Description automatically generated

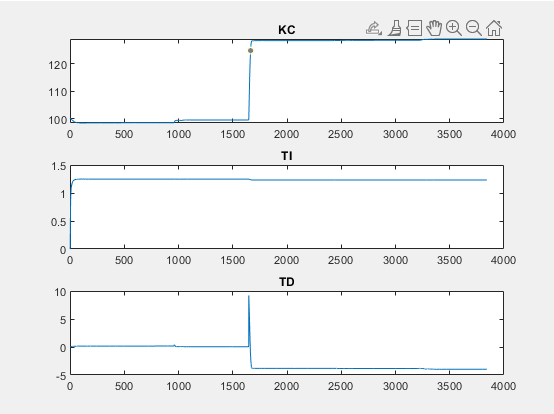
RLS Optimum

Chart, line chart

Description automatically generated

Chart, histogram

Description automatically generated



PID without Anti Wind-up

Chart, histogram

Description automatically generated

Chart, histogram

Description automatically generated

PID With AWD (tt) = 7

Chart, histogram

Description automatically generated

**6. CONCLUSION**

This paper focus on comparison of conventional and Adaptive PID for pH controller on wastewater threatment. The objective of this pH controller is following the desired neutral pH value. This problem was solved using Adaptive PID. This work gives an alternative method which is better than previous ones in controlling the pH value.

**7. REFERENCES**