Chapter 4
CHAPTER 4

FLC FOR AUTOMATIC TIDE GENERATOR (ATG) SYSTEM
(A REAL TIME APPLICATION)

4.1 INTRODUCTION

Before the construction of any coastal or offshore structures like port, jetty, pier, the stability of the structure, ecological impact, siltation problems are analyzed using miniature physical models (Damle P.M. 1952). The conditions of tide, water current, wave pattern of the coastal area where the structure is to be constructed are simulated in the miniature model. Automatic Tide Generator (ATG) system is an equipment used to simulate tide cycle in these models. ATG system is a level control system by which identical condition of tide cycle is produced. Thus water current as in the coastal area is produced in the physical model at reduced time geometrical scale.

Fuzzy logic is used for various process control applications. In this chapter, Fuzzy Logic Controller (FLC) for Automatic Tide Generator (ATG) system is furnished. The construction and orientation of the physical model is varied during the experimental studies (Kalt A. 1982). This control process is non-linear in nature because of frequent variation in the physical model and also due to the use of non-linear out flow control gates. Instead of the PID controller which is initially used in the ATG system, the proposed FLC is used and they are compared. The robustness of FLC is proved by a case study in which the same ATG system is used for two different models.

The performance of the proposed FLC and the conventional controller viz. PID controller are compared and enumerated in this chapter along with the brief description of ATG system. When PID controller is used, two separate algorithm with different controller setting are needed. But if FLC is used, the same algorithm could be used for both models.
This chapter is organized as follows: In section 2 a brief description of ATG system is given. In section 3 design procedure of FLC for ATG system is given. The implementation of the proposed controller in real time along with case study is given in section 4. Remarks about the results are given in section 5.

4.2 ATG SYSTEM

The topological features of the shore line are geometrically reduced and constructed in the model area. The model area is 15000 m² (approx.). The sketch in Fig. 4.1 shows the ATG system as a physical model. The ATG system consists of a wild inflow channel called supply channel, which supplies 15000 lps (approx.) of water to the model through a series of supply tubes. The water level is maintained by controlling the outflow by using a series of drainage gates which are keyed to a shaft. A stepper motor rotates the shaft to change the position of these gates and manipulates outflow. A similar control system is discussed by (Layne J.R. and Pasino K.M. 1993) where the rudder position is controlled. Water drains into drainage channel and to the re-circulation tank. The water level at different parts of the model is measured accurately by capacitance type level transmitters. By using personal computer based control system, the desired water level in the model is maintained. The conventional PID control is programmed in software in personal computer 486 system. The proposed FLC software replaces the PID control algorithm software. The software is developed using C++ programming language (Stroustrup Bjarne 1991).

4.2.1 Control System components

The block diagram of the control system used in ATG system is shown in Fig. 4.2. The desired level or the tide condition (that is the set point to the system) is stored in a data file in the hard disk of the personal computer. The range of water level to be maintained in the model is 0.8-20.4 cm. The actual water level at the required point is measured accurately by a capacitance type level transmitter, whose span is 0-50 cm. The transmitter is calibrated and the span is adjusted to give an output in the range 4-20 mA. The output of the level transmitter is filtered for noise using a second order
The computer (controller algorithm) controls the opening or closing of outflow drainage gates and manipulates the outflow of water to maintain the desired level in the model. The one byte magnitude output of control algorithm viz. PID/FLC in the range 0-2^8(255) is used to generate pulses of the frequency range 1-200 Hz using the timer of interface circuit viz. PCL 223. The pulse generated is fed to a heavy duty stepper motor driver supplying high current to the coils of stepper motor. The stepper motor shaft is connected to a gear box which transmits the torque to a shaft, where 16 outflow gates are mounted. The relation between the gate opening and the flow is non-linear. The opening or closing is decided by the sign of the output of control algorithm communicated by sign bit or direction bit.

4.2.2 Signal Processing

The level transmitter is of capacitance type giving an output signal 4- 20 mA which is further converted into 0- 10 V (dc), for the selected span. The accuracy of the instrument is ±1% of the scale. The span selected is 0-50 cm and the response time is 20 nano second.

The signal from level transmitter is converted into digital signal using Analog to Digital Converter (ADC). The ADC-674 used has 12 bit resolution and its conversion time is 25 micro seconds. The data is read by the computer and converted into real time unit and normalized at a sampling time of 1 second. Control algorithm calculates the direction and speed of stepper motor to open or close the drainage gates.
4.2.3 Variable Frequency Synthesizer

The magnitude of the output of the control algorithm is converted into one byte data and written on the parallel interface card PCL 223, which has a timer circuit. The timer is used as the variable frequency synthesizer.

The duty cycle of pulse can be varied by a 8 bit counter in the timer circuit. The one byte data of the control algorithm written on interface port of the PCL 223 card determines the duty cycle of the pulse generated. The time period of the pulse generated ranges from 5 milli second to 1 second which is fed to the stepper motor driver.

4.2.4 Stepper Motor driver

The stepper motor consists of four coils and when signal sequence shown in Table 4.1 is supplied to the coils, the rotor rotates by one step in clock wise direction. If the above sequence is reversed, the rotor rotates one step anti clock wise direction (Charles A. Schuler and William L. McNamie 1986).

<table>
<thead>
<tr>
<th>No</th>
<th>Sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>coil 1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 4.1 Sequence for driving stepper motor in clock-wise direction

For each pulse generated by the variable frequency synthesizer, the stepper motor driver produces one set of sequence as per the direction sign bit for clock wise direction or for anti clock wise direction. The sign bit or the direction bit of the control
algorithm is communicated to the stepper motor driver unit through the 8255 interface chip of PCL 223 card which supply +5v for clock wise rotation or -5v for anti clock-wise rotation. The driver unit supplies high current in the range of 5 ampere per coil, as the stepper motor has to drive heavy load and has the capacity to produce 30 kg torque.

The rotor shaft of the stepper motor is connected to a gear box having transmission ratio 100:1. The gear box transmits torque to the shaft where sixteen gates are keyed which are opened or closed (Stuart Bennett 1988).

4.3 FUZZY LOGIC CONTROLLER

The FLC type II discussed in chapter 2 is implemented in real time for ATG system. The Fuzzy Logic Controller (FLC) consist of three modules namely Fuzzification Module, Rule base, Defuzzification Module. The block diagram of FLC is shown in Fig 4.3. The design of each blocks are discussed below.

4.3.1 Fuzzification

The interacting variable such as control variable, load variable and manipulated variable are identified. The level is the control variable, change in physical model is the load and the outflow through the gates to drainage channel is the manipulated variable. The system does not have mathematical model and even if the mathematical model is found the system parameters keep changing.

The input to the controller are error e(k) and change in error Δe(k). The output of the controller is ‘change in controller output’ Δu(k). These crisp inputs are converted into linguistic values of Fuzzy Sets using fuzzifier.

The error e(k), change in error Δe(k) and ‘change in controller output’ Δu(k) are fuzzified into 8 linguistic variables viz. PB, PM, PS, PZE, NZE, NS, NM, and NB.
respectively. The membership function of all these linguistic sets is assigned using bilinear transformation.

The membership function for these linguistic sets are assigned in such a way that there is 25% maximum overlap. This value is arrived by trial and error. The membership function for error, change in error and output are shown in Fig. 4.4- 4.6 respectively.

4.3.2 Rule base

The approaches for deriving the rules of the rule-base may be categorized into heuristic method and deterministic method. In this application deterministic method is followed to form the rule-base. The dynamics of the model is similar to over damped second order system. So rule-base discussed in chapter 2, section 2.4.2 is used.

4.3.3 Defuzzification

The output of the rule base should be converted into crisp value. This task is done by defuzzification module. Maxima criterion, Mean of Maxima and Centre of Area method of Defuzzification are considered in chapter 2 and out of them Center of Area (COA) method of defuzzification is giving good results for over damped second order system. So the Centre of Area (COA) method of defuzzification strategy is followed. The output is the resultant of rule-base, which is calculated using the formula given in equation (4.1)

\[
y_o = \frac{\int B(y) \, y \, dy}{\int B(y) \, dy} \quad (4.1)
\]

where \(y_o\) is the crisp value, \(y\) is the variable and \(B(y)\) is membership function.
4.4 REAL TIME IMPLEMENTATION

The tide data acquired by field survey is scaled down to the geometrical (1000:1) scale of the model. To have reliable results the control should be in terms of tenth of millimeter, because 10 cm rise in tide level in the field survey corresponds to 1/10th of mm in the model. One tide cycle of the field survey data for JNPT, Mumbai is given in Fig. 4.7 and the scaled down data which is set point to ATG system is given in Fig. 4.8. The control algorithm maintains the water level in the model, so that the deviation is minimum from the set point to reproduce the exact tide cycle as in the site.

4.4.1 PID controller

The ATG system has PID controller before the proposed controller is installed. The controller parameter viz. proportional gain $K_p$, integral time $T_i$ and derivative time $T_d$ are determined by extensive trial and error method. The continuous form of PID algorithm is given in equation (4.2).

$$m(t) = K_p e(t) + \frac{1}{T_i} \int_0^t e(t) \, dt + T_d \frac{de(t)}{dt} + m_0 \quad \text{......... (4.2)}$$

The controller parameters are $K_p = 4.2$, $T_i = 8$ seconds, $T_d = 4$ seconds.

The continuous form of control algorithm in (4.2) is discretized to digital form which is given in equation (4.3) The output of the controller is normalized to 8 bit data. The sign of the controller output sets the direction bit or sign bit which determines the direction of rotation of the stepper motor.

$$m(k) = K_p \left(1 + \frac{T_i}{T_s} + \frac{T_d}{T_s}\right) e(k) + K_p \left(1 + 2 \frac{T_d}{T_s}\right) e(k-1) + K_p \left(\frac{T_i}{T_s}\right) e(k-2) + m(k-1) \quad \text{......... (4.3)}$$

where $T_s$ is the sampling time.
4.4.2 Comparison Analysis

The PID controller is used in the ATG system in the physical model for the tide studies of JNPT, Mumbai. The tide produced by ATG system using PID controller is shown Fig 4.9. Then FLC proposed in section 4.3 is used for the same studies. The tide produced by using FLC is shown in Fig. 4.10.

The PID controller is tuned by many trials and FLC is also tuned for membership function i.e. over lap of membership function of linguistic variables and the universe of discourse of variables etc. by equal number of trials. So the labor for tuning both the controller are more or less equal. But when major modification is made in the model, the performance of PID controller deteriorates and requires further tuning. But the performance of FLC is stable. The details of IAE, maximum error for the two controllers are given in Table 4.2.

<table>
<thead>
<tr>
<th></th>
<th>PID</th>
<th>FLC</th>
</tr>
</thead>
<tbody>
<tr>
<td>IAE</td>
<td>220</td>
<td>195</td>
</tr>
<tr>
<td>MAXIMUM ERROR</td>
<td>8%</td>
<td>4%</td>
</tr>
</tbody>
</table>

Table 4.2. Comparison of performance of PID and FLC for ATG system

4.4.3 Case Study

When JNPT, Mumbai model studies are going on, another study i.e. Essar oil, Gujrat pier siltation problem was conducted. A separate model is built adjacent to JNPT model. The ATG used for JNPT, Mumbai is used by extending the shaft where gates are keyed and attaching 8 more gates with the shaft. The sixteen gates of the JNPT model are disengaged from the shaft, when the study is going on at the new model. It should be noted that both the studies are not undertaken simultaneously, because ATG system can be used by only one model at the time.
The field survey data collected for Essar oil is shown in Fig. 4.11. The PID controller used for JNPT, Mumbai model is used for the new model (Essar oil). But the performance of the PID controller is so bad that it requires tuning. The performance is shown in Fig. 4.12.

But when the FLC used for JNPT, Mumbai model studies is used for the new model, the performance of the ATG system is good. Tide condition is obtained in the field survey is reproduced at the model by using FLC without tuning. The performance is shown in Fig. 4.13.

4.5 RESULT AND DISCUSSION

In this chapter design and real time implementation of FLC for ATG system is furnished. The performance of FLC is as good as PID controller when there is no physical change in the model. When major changes in construction is done in the physical model, the performance of PID controller deteriorates but FLC performs better than the PID controller and it was similar to earlier good performance.

When the same control algorithm need to be used for another model, PID controller fails and it requires tuning. It is found that FLC can be used successfully without tuning. So if FLC is used in this situation, lot of labor can saved.

It is also observed that though the rule base consists of 64 rules, only 40 rules are actively used. The firing of the remaining 24 rules are mostly nil as the same are meant for tackling extreme condition of load or set-point variation. To improve the computational efficiency the rule base should be optimized. Based on this problem a FLC is proposed in chapter 5 where the rule base is optimized using expert system ideas.
Fig. 4.1 Physical model and ATG system
Fig 4.2 ATG control system

Fig 4.3 PID controller based feedback control system for ATG
Fig 4.4 Membership function of linguistic variables of error (real time unit)
Fig. 4.5 Membership function of linguistic variables change in error (real time unit)
Membership function of linguistic variables of output FLC (frequency change)
Fig. 4.7 Tide data collected for JNPT, Mumbai by field survey
Fig 4.8  Scaled down tide data for JNPT, Mumbai studies
Fig 4.9 Performance (set-point tracking) of PID controller for JNPT model
Fig 4.10  Performance (set-point tracking) of FLC for JNPT model
Tide data (set-point) for Essar oil siltation studies
Fig 4.12   Performance (set-point tracking) of PID controller for Essar Oil
Performance (set-point tracking) of FLC for Essar Oil

Fig. 4.13