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Embedded System Design for Canal Gate Automation

Shashikumar P. Tale[1], A. R. Khaladkar[2], Mukesh Arora[3], S. K. Shah[4]

PG Student, Dept. of E & TC, STES Smt. Kashibai Navale College of Engineering, Pune, India [1]

Scientist C, Central Water and Power Research Station, Pune, India [2]

Scientist B, Central Water and Power Research Station, Pune, India [3]

HOD PG, Dept. of E & TC, STES Smt. Kashibai Navale College of Engineering, Pune, India[4]

Abstract: The water discharge from the canal depends on the various canal parameters viz. upstream water level, downstream water level, canal dimensions, etc. For the correct water distribution, the upstream and downstream water levels need to be maintained properly. Continuous discharge of water at constant rate is can be achieved by keeping the difference between upstream and downstream water levels constant. The canal gate opening needs to be corrected according to the changes in the upstream water level, desired water discharge, flow rates, etc. The Proportional Integral Derivative (PID) control algorithms are robust and efficient to achieve zero steady state error. Thus in order to maintain the correct the gate position, PID algorithm can be used. A PID algorithm based embedded system is implemented to maintain the upstream water level in the canal at constant desired level. The implemented system maintains the desired upstream water level within the acceptable tolerance limits.

Keywords: Upstream water level, downstream water level, canal dimension, PID algorithm.

I. INTRODUCTION

With the rapid increase in human population and the increasing industrialization the water resources are consumed heavily. Thus the water is becoming a more care resource over the world. As the population is growing and the economy is increasing, the direct fresh water consumption viz. the drinking water, water for washing is increasing dramatically. The indirect water uses like the irrigation water for industry and agriculture is also increasing. Thus, a proper management of water consumption and the available water is very necessary for sustainable development. Hence more accurate and flexible irrigation canal systems are required.

The proposed system automatically maintains the upstream water level to the desired set point for a given flow of water in the canal. Also provides the adaptive measure to control the response of the system for minimizing the system oscillations.

A. Downstream Water Level Control Method

In the downstream control method the canal gate structure is operated to control the downstream water level of the canal pool.When the downstream water level shows the deviation from the desired set point, the information is communicated to the controlling structure at upstream point. The controlling structure then takes corrective action to compensate the downstream error. For the positive error the upstream gate should open and for negative error the canal gate should closed appropriately.

B. Upstream Water Level Control Method

In the upstream control method the situation is exact opposite to that of downstream water level control method. In this, the canal gate structure is operated to control the upstream water level of the canal pool. When the upstream water level shows the deviation from the desired set point, the information is communicated to the controlling structure at downstream point. The controlling structure then takes corrective action to compensate the upstream error. For the positive error the upstream gate should close and for negative error the canal gate should open accordingly.

II. RELATED WORK

The PID algorithm is very robust and effective in control system. It is widely used in closed loop systems where a particular system variable needs to maintain the desired set point value. Some such closed loop systems are discussed below.

A downstream control in canal automation using software approach is discussed in [1]. In this a PID algorithm is developed using the PID controller tool set of LabVIEW software. Also it discusses about the NI MyRIO real time processor having NI LabVIEW and its features for development of canal automation system based on PID algorithm.

An upstream control in canal automation using PI controller is discussed in [2]. PI controllers are the special case of PID controllers in which the D i.e. derivative gain is kept zero. In this paper velocity form of PI logic is presented. A new concept of universal factor is introduced which accounts for the nonlinearity in the water level to gate response. The tuning of PI logic over widely varying flow rates is presented in this paper.

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An adaptive PID algorithm to control the speed of a separately excited DC motor is discussed in [3]. In this paper, a dynamic sliding mode control technique along with the PID algorithm is introduced for DC motor control. Also the improvement in performance by the use of adaptive feature of PID is discussed along with the simulation results.

A DC motor speed control using linear quadratic regulation (LQR) is discussed in [4]. In this paper the linear quadratic regulation (LQR) based tuning of the gains of PID is given. Also, the state weighting matrices method of LQR for finding the set of optimal PID gains is introduced. It is used for second order plus time delay (SOPTD) process utilizing the pole placement techniques.

A self-tuning PID control for permanent magnet synchronous motor (PMSM) is discussed in [5]. An energy-based approach to PMSM control with parameters self-tuning PID control is introduced. The self -tuning PID achieves good speed tracking motion by keeping the system's total energy to the desired value. The port-controlled Hamiltonian structure of PMSM system is presented.

A PID controller designed for position control of DC servo-motor is discussed in [6]. An Integral-Square-Error (ISE) minimization method is introduced which. The formulated ISE is minimized using the Luus-Jaakola (LJ) algorithm. Also, the results of LJ algorithm are compared with the Ziegler-Nichols (ZN) algorithm.

A novel feedback mechanism for the conventional proportional integral controller is discussed in [7]. In this paper current regulation using PI controller which is PID controller with derivative term zero is given. Also an approach to eliminate the steady-state error of the grid current at the fundamental frequency is presented.

There are a number of methods for tuning the PID parameters. The response of the PID algorithm depends on the values of the PID parameters. The response requirements of the different systems differ widely. There is no specific method of parameter tuning which will suite for all the systems. The different tuning methods are discussed in following paper.

The different recent PID parameters tuning methods required for design of PID controller are discussed in [8]. The tuning methods like Ziegler-Nichols (ZNI) method, Kappa-tau tuning, Pole placement, D-partitioning, Nyquist based design, PID tuning using the theory of adaptive interaction, Methods based on cancellation, K-B parameterization, Frequency loop shaping (FLS) method are discussed along with their advantages and disadvantages.

III.CANAL GATE AUTOMATION SYSTEM

The figure 1 shows the block diagram of Canal Gate Automation System which consists of water level sensor, Controller which works on PID algorithm, Motor driver and Shaft encoder.The system is designed around Arduino MEGA 2560 controller board. It runs the PID algorithm, takes water level from HC SR05 sensor and drives the motor through designed h-bridge motor driver. The ultrasonic transceiver modules are used for measuring the upstream and downstream water levels. The upstream water level is of more interest as the canal models use mainly the upstream water level control methods. The ultrasonic signals are the signals with the frequencies above 20 kHz. The human ear has upper audible limit of 20 kHz so cannot hear the ultrasonic sound. The ultrasonic sensor module HC SR05 is used for measuring the water levels.

The ultrasonic module HC SR05 is used for measuring the water level in the canal. The module has four pins viz. VCC, GND, ECHO and TRIGGER. A supply of 5V is sufficient for the normal module working. A high pulse of 10µs is needed to be fed to the TRIGGER pin to start the module functioning. When a trigger pulse is supplied to the module it transmits a burst of 40 kHz ultrasonic sound and makes the ECHO pin high till it receives back the corresponding echo signal. The duration of the high pulse gives the time (T) taken by the burst to traverse the path from module to target and back to module. Thus, the distance (D) of water level from the module can be calculated as:

$$\text{Distance (D)} = \frac{\text{velocity (v) of sound in air}}{0.5 * \text{T}}$$

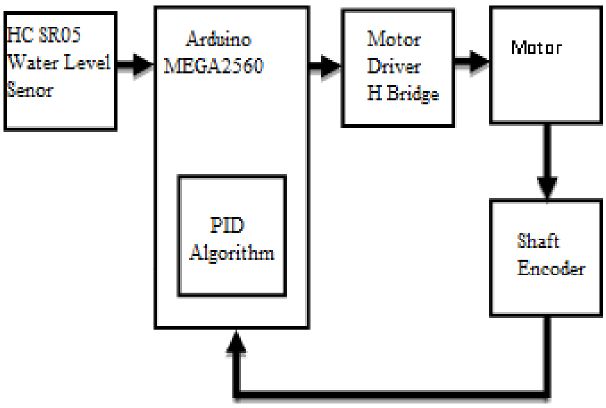

Fig 1: Block Diagram of canal gate automation system

The velocity of sound in dry air is around 343m/s. The actual water level (h) in the canal is computed by subtracting the distance (D) from the depth D_0 of the canal base.

$$\text{Height of Water (h)} = \text{canal depth } (D_0) - \text{ Dist (D)}$$

The flowing water produces continuously changing dynamic waves which differ in heights. This creates random fluctuations in determining the water height in canal. The effect harmonics causes deviation from the true value of the water level. This effect can be minimized by taking a number of samples $(S_1, S_2, S_3, \dots, S_n)$ and finding the mean S_m of their total. It is given by:

$$S_m = \frac{S_1 + S_2 + S_3 + \cdots + S_n}{n}$$

where n is number of samples. The mean value S_m gives the water level close to the true value of the actual water level.

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The PID algorithm is a robust, flexible control algorithm which leads the closed loop system towards the zero steady state error. The response of the PID algorithm depends on the P, I, D coefficients and the error (e) which is the deviation of actual process variable and set point. The upstream water level is the process variable in the proposed system. The PID algorithm program is dumped in the microcontroller. Thus, it acts as the PID controller. The P, I, D and the desired set point are fixed through programming. The controller gets the input from the level sensors. The controller determines the difference between the actual water level and the set point upstream water level. This gives out the amount of error signal. The controller then computes the amount of response required to achieve zero error signal.

A 12V DC motor is used to drive the mechanical gate control structure. The motor shaft drives the geared assembly which reduces the load on motor shaft. The canal gate is attached directly to the geared assembly. The motor draws high current due to loaded condition. The motor is controlled through pulse width modulation (PWM). In order to drive the motor with high current through pulses a motor driver is necessary. The commercially available high current PWM H-Bridge motor drivers ICs are expensive. Thus, a custom high current PWM controlled H-Bridge circuit is designed. It contains 2 PNP and 2 NPN power transistors, 4 base current control registers, 4 freewheeling diodes to pass back electromotive force and heat sinks as pulsating high currents heats up the power transistors.

The gate needs to be driven precisely to produce the correct output deviation. Thus, for the controlled shaft rotations the shaft encoder is attached with the motor shaft. The shaft encoder contains a circular opaque disk with small hole on its perimeter. There are two LEDs and two phototransistors on either side. It tracks the direction and amount of rotations of the motor. The data related to the gate opening is thus tracked using shaft encoder which feeds to the controller.

IV. SYSTEM FLOW

Logic flow of system is as follows and shown in figure 2.

1. Initially the values of P, I and D coefficients are determined and set.
2. The upstream water level is continuously read.
3. The deviation of the upstream water level from the set point is computed.
4. The PID algorithm computes the response as per the error signal value generated because of the difference between the desired water level and actual water level in the canal.
5. The motor is then operated accordingly so that error value tends toward zero.

The shaft encoder data is read continuously for the period of motor movement. The encoder tracks the direction and number of revolutions of motor.

Steps 2 to 5 are repeated till the upstream water level stabilizes in the allowable tolerance limits.

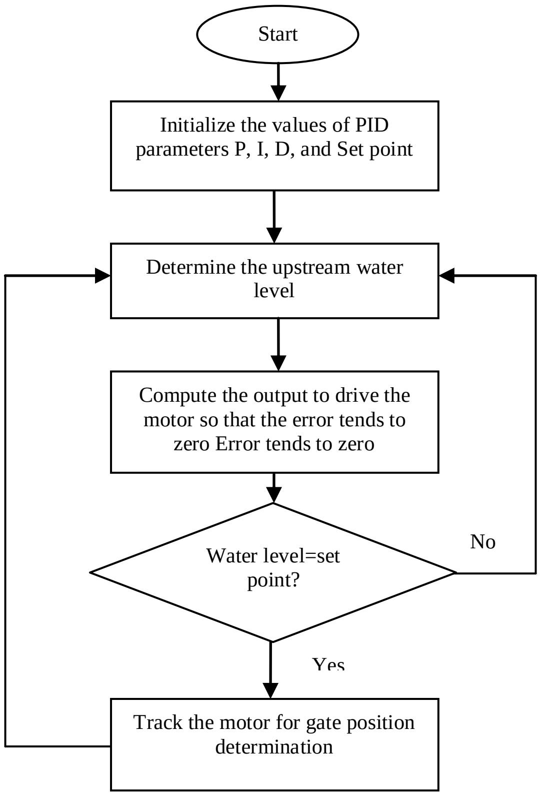

Fig 2: Flow chart of canal automation system

V. RESULTS

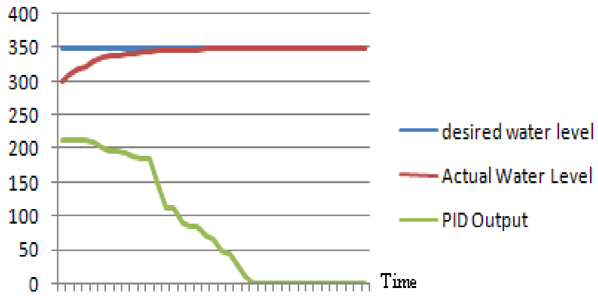

Fig 3: PID output of system with DWL > AWL

The figure 3 shows the PID output generated by first instantiation of PID algorithm when desired water level (DWL) is greater than actual water level (AWL). The above plot clearly shows that with the positive error the designed system achieves the zero steady state error within short time interval. The PID output is a function of the error generated between the two water levels.

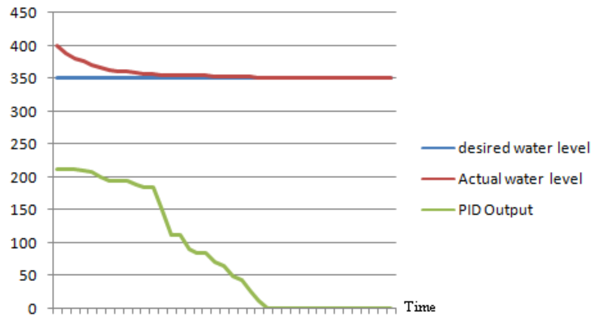

Fig 4: PID output of system with DWL <AWL

The figure 4 shows the PID output generated by second instantiation of PID algorithm when desired water level (DWL) is lesser than actual water level (AWL). This plot also shows that with negative error also the designed system achieves the zero steady state error within short time interval.

VI. CONCLUSION

The canal gate automation is needed for making the canal system responsive to the changes in the water level. The designed system is able to monitor water levels continuously and control as desired. The closed loop control is achieved by using the PID algorithm. The PID algorithm addresses the error due to deviation of actual water level from the desired water level in very less time. The designed standalone system is completely scalable as per the number of canal gates to be monitored and controlled. Thus, the designed system provides a robust, time efficient, scalable solution for canal gate automation.

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