2024 Tenth Indian Control Conference (ICC)
9 - 11 December, 2024
IISER Bhopal, India

Single tank PID-based liquid level controller using low-cost level sensor and in-house developed valve actuator system for control education

Sri Hari Prasath Ramprasad[1], Harish Doneparthi[2], Harish Babu[3], Rohit Raphael[4] and Sridharakumar Narasimhan[5]

***Abstract*— Maintaining a precise liquid level is crucial for safety and efficiency in many industries. Various control algorithms can be used to keep the same, such as Model predictive control (MPC), Proportional-Integral-Derivative (PID), etc. These controllers use sensor feedback to monitor the liquid level and adjust valves or pumps accordingly. In this paper, we describe an experimental test bed equipped with a low-cost level sensor and an in-house developed valve actuation system, which can be combined with any commercially available quarter-turn valve to conduct an educational experiment to help students understand the theory and functional logic behind the PID based liquid level controller.**

I. Introduction

In a control system, the process variable is the system parameter that needs to be controlled, such as level (m), temperature (ºC) etc. The value measured by the sensor feedback is the process variable of the control system. The difference between the process variable and the desired set point is continuously calculated and is used by the algorithm (controller) to control the actuator output accordingly. A typical PID controller reads the sensor value and then computes the proportional, integral, and derivative responses and sums those three components to compute the desired actuator output.

Maintaining a precise liquid level is crucial in industries such as water treatment, chemical processing, oil refining etc for safety and efficiency. Level control theory and experiments are typically included in an undergraduate control course. A pneumatic control valve is bulky and requires a compressor. Although a small factor electrically actuated control valves are now available, they are expensive. In this contribution, we have developed a low-cost servo motor-controlled valve which can continuously be controlled by controlling its angle.

*This work was partially supported by Department of Science and Technology, Govt. of India

[1]Sri Hari Prasath Ramprasad is a Research scholar in the Department of Chemical Engineering, Indian Institute of Technology Madras, Chennai, India srihari98prasath@gmail.com

[2]Harish Doneparthi is a Research scholar in the Department of Chemical Engineering, Indian Institute of Technology Madras, Chennai, India ch23d027@smail.iitm.ac.in

[3]Harish Babu is a Project Associate in the Department of Chemical Engineering, Indian Institute of Technology Madras, Chennai, India harishb2002bh@gmail.com

[4]Rohit Raphael is a Research scholar in the Department of Chemical Engineering, Indian Institute of Technology Madras, Chennai, India rohitraphael@gmail.com

[5]Sridharakumar Narasimhan is a Professor in the Department of Chemical Engineering, Indian Institute of Technology Madras, Chennai, India sridharkrn@iitm.ac.in

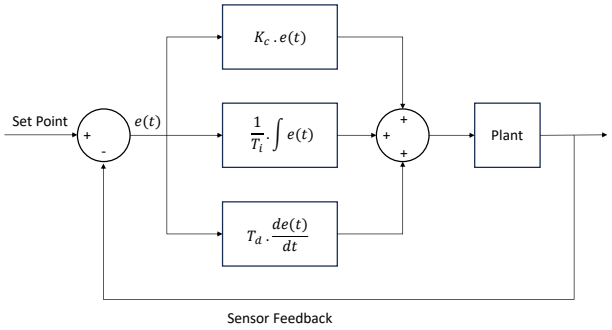


Fig. 1. Block Diagram of a basic Closed loop PID control algorithm

II. System Overview

The single-tank system is influenced by the inflow (disturbance) and outflow (controlled), and the dynamic interaction between these leads to fluctuations in the liquid level within the tank. Outflow is controlled by a 1/4 turn valve, which determines the drain rate. If the inflow is less than the outflow, the liquid level in the tank decreases. This dynamic balance is crucial for maintaining the desired liquid level and is often managed through feedback control systems like PID controllers. Controller tuning is important to obtain acceptable closed-loop performance and this requires data collection in an open-loop system.

III. Experimental Setup

A. Hardware

To initiate the experiment, the following hardware setup is required:

- **A single tank with an independent inlet (Disturbance)** through which the water is fed at a constant flow rate (Fig. 3).
- **Arduino-based Micro-controller** with appropriate Digital I/O pins(Fig. 4).
- **HC-SR04 Ultrasonic lever sensor** which senses the distance between the sensor and the surface of the water using **the time of flight** principle which can be interpreted as water level values by subtracting the sensed distance from the total height of the tank(Fig. 5).
- **Servo actuated outlet valve** which controls the valve position between **0% to 100%**, where 0% corresponds to fully closed and 100% corresponds to fully open. A servo motor is coupled with a commercial PVC

valve using a 3D-printed fixture. The servo motor is fed with an angle using the Arduino-based Microcontroller which in turn results in controlling the valve opening (Fig. 6). The overall production cost of this valve is less than Rs. 2500 while the commercially available valve of the same orifice is priced between Rs.50,000 to 70,000.

- **A 5V power supply** to power the Servo motor, Ultrasonic sensor, and Microcontroller.

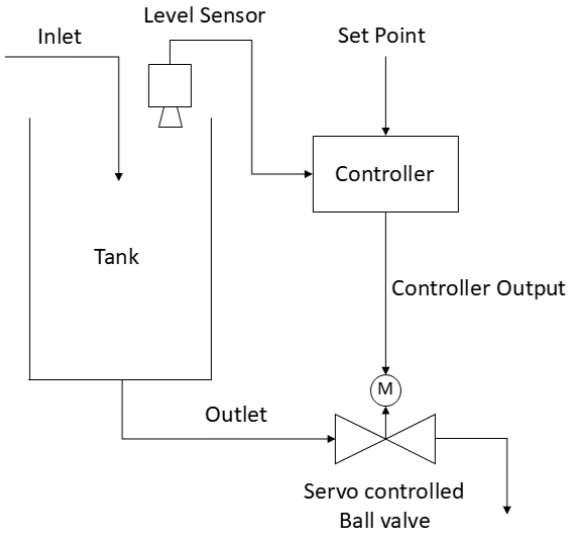


Fig. 2. PID-based Liquid Level Control Block Diagram



Fig. 3. A single tank with independent inlet

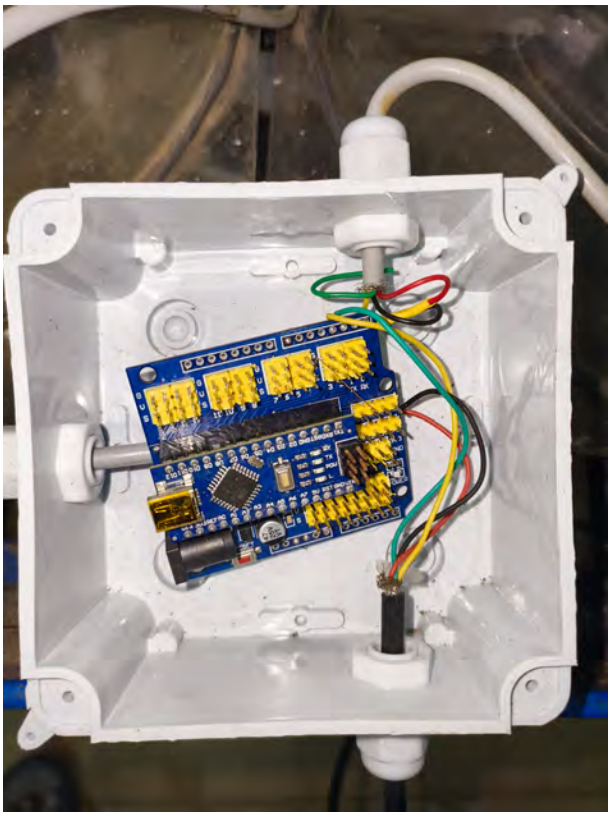


Fig. 4. Arduino Nano Micro-controller

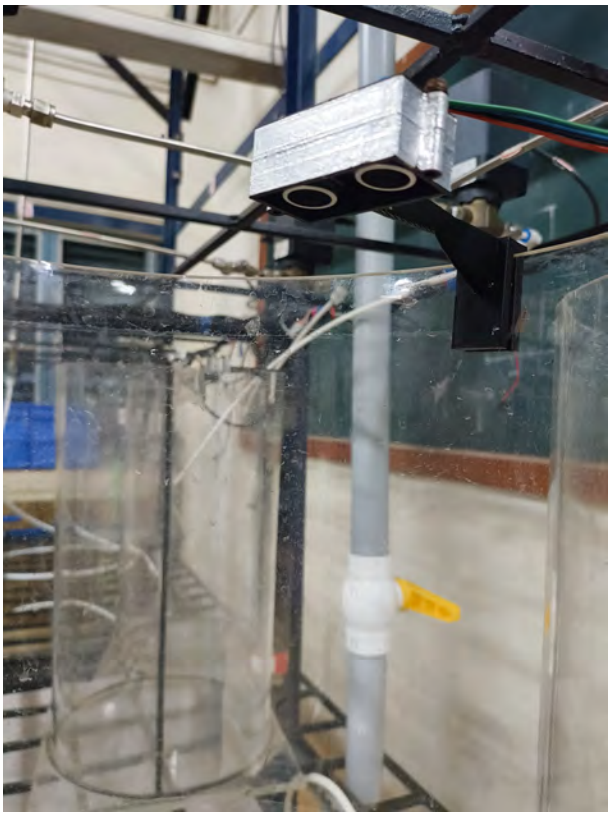


Fig. 5. HC-SR04 Ultrasonic sensor installed on the tank

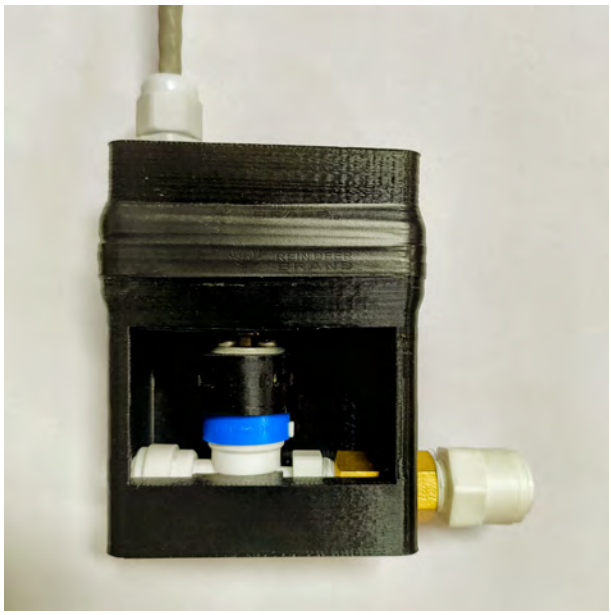


Fig. 6. Servo motor coupled with 1/4 inch PVC valve inside a 3D printed housing

The cost of the entire set-up is Rs. 3,000 (Excluding the tank). Fabrication of the system can be included as an exercise for students in an advanced instrumentation course.

B. Software

For data acquisition and to program the controller with appropriate PID parameters, Arduino IDE shall be used with appropriate libraries such as NewPing.h, Servo.h, and PID_v1.h

IV. Procedure

The controller tuning is based on modified Ziegler Nichols tuning rules [1].In the single-tank system, first, we have to make sure that the in-flow rate is constant. The outlet valve is set to a certain percentage of the opening. If the out-flow rate is lower than the in-flow rate, we can observe an increase in water level. After a few minutes, a significant change in the valve opening is applied. The system will react to this change accordingly after a small interval and we can notice the level getting changed (Increase/Decrease) based on the difference in the valve position. Once the data is collected, it will be plotted with respect to time. Now we can observe two different slopes for particular time intervals collected with two different valve positions.

V. Estimation of PID Parameters using Modified Ziegler-Nichols method

A. Controller tuning

The trend lines for both slopes are drawn and extended until both lines intersect. The time difference between the change in valve opening and the intersection of the slopes is the dead time (td) of the system which is the primary parameter required for tuning the controller. The change control valve position is the difference in controller output (dCO) which is denoted in %. The difference between the slopes (DS) of the two lines plotted earlier, was found.

$$DS = \frac{PV_4 - PV_3}{T_2} - \frac{PV_2 - PV_1}{T_1}$$

where, PV1 & PV2 are the process variables of slope 1 and PV3 & PV4 are the process variables of slope 2. T1 and T2 are the time interval PV1 & PV2 and PV3 & PV4 respectively.

The process integration rate (ri) can be calculated using the percentage of difference in slope (DS%).

$$DS\% = 100 \times \frac{DS}{\text{(PV range max - PV range min)}}$$

$$ri = \frac{DS\%}{dCO}$$

With the parameters obtained from the experiment, we can calculate the tuning parameters for the PID controller:[1]

$$K_c = K_p = \frac{1.2}{SM \times ri \times t_d}$$

$$T_i = 2 \times SM \times t_d$$

$$K_i = \frac{K_p}{T_i}$$

$$T_d = \frac{t_d}{2}$$

$$K_d = K_p \times T_d$$

where K_c or K_p is the controller gain, T_i is the integral time constant,K_i is the integral gain, T_d is the derivative time constant, K_d is the derivative gain and SM is the stability margin.[1]

The degree of de-tuning is defined by the stability margin, which is maintained at 2 or greater.[1]

After finding the tuning parameters, they can be applied to the system for different in-flow rates.

B. Parameters obtained from the data

All the parameters are converted to SI units.
$PV1 = 0.1731$ m
$PV2 = 0.1872$ m
$T1 = 192.18$ s (Difference in time between PV1 and PV2)
$dCO = 47\%$
$PV3 = 0.1872$ m
$PV4 = 0.1719$ m
$T2 = 59.8s$ (Difference in time between PV3 and PV4)
$t_d = 0.065$ (time in seconds)

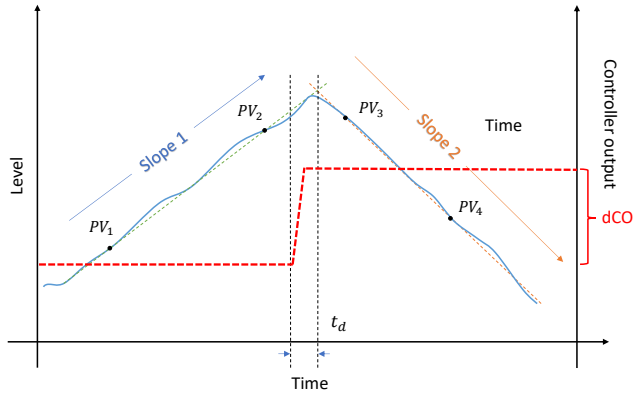


Fig. 7. Open-loop data collection using the single-tank level controller [1]

C. Results

Based on the formulas and parameters obtained from the data collected, the calculations are as follows:

$$DS = -0.000329 \tag{1}$$
$$DS\% = 0.0823 \tag{2}$$
$$ri = 0.00175 \tag{3}$$
$$K_c = K_p = 5271.175 \tag{4}$$
$$T_i = 0.26 \tag{5}$$
$$K_i = 20273.752 \tag{6}$$
$$T_d = 0.0325 \tag{7}$$
$$K_d = 171.313 \tag{8}$$

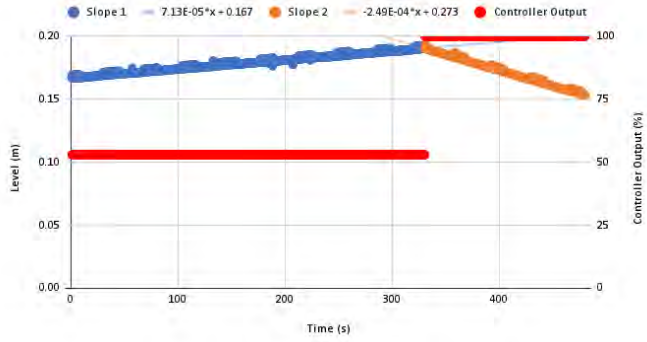


Fig. 8. Experimental data collected using Open-loop controller

VI. Results

The PID parameters obtained from the calculation were used in the Arduino program and closed-loop response was collected as shown in Figs. 9 and 10.

VII. Conclusion

Based on the open-loop data collected, the PID parameters are estimated, and the controller is programmed to maintain the liquid level at the desired set point, effectively compensating for any changes in the inflow rate (disturbance).

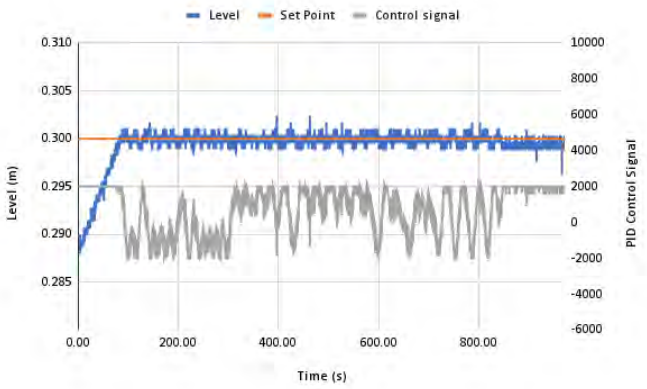


Fig. 9. Closed-loop response of the system

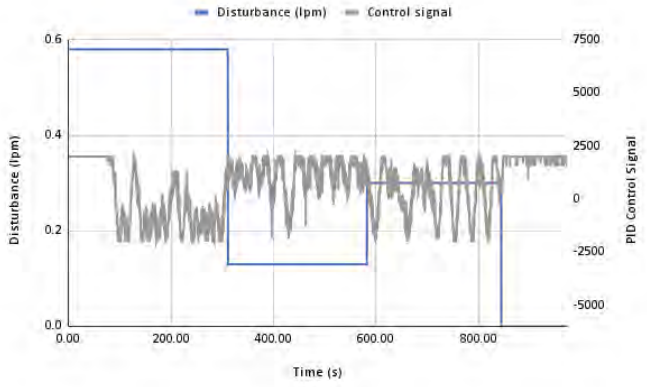


Fig. 10. Response of the PID controller for change in disturbance

The process of data collection and closed-loop response are shown in the YouTube video link `https://youtu.be/3a0I6hUJ-_s`.

References

[1] Smuts, Jacques (16 Dec,2011). "Level Controller Tuning." OptiControls, `https://blog.opticontrols.com/archives/697`.