Title

Controlling an Infinity Fountain Infinitely

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Controlling an Infinity Fountain Infinitely

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Objective

This experiment was designed to allow for the exploration of different types of process controllers. Properties of proportional (P), derivative (D), integral (I), and combinations of these controllers were investigated when exposed to a set point change. Furthermore, the impact of tuning on the PID controller was studied by using the Ziegler-Nichols optimization technique. It is predicted that PID controller will perform the best because it the derivative controller will prevent any big oscillation and the integral controller will take care of any offset making it have a fast response. Moreover, tuning the PID controller will make it respond better to any disturbances that may take place.

Motivation

Process Controllers, specifically PID Controllers, are used in industry to maintain control over industrial processes, such as temperature, pressure, and flow rate. Controllers are able to detect abnormalities and ensure the process operates within the desired range, reducing overall risks. PID Controllers can be tuned to further optimize the process conditions, saving money and increasing productivity.

Industrial Applications:

- Oil and Gas - Oil and gas are refined to the correct specifications, such as purity and composition.
- Pharmaceuticals - Correct quantities of ingredients are used and created at the correct conditions.
- Petrochemical - Polymerization process with the correct catalysts and initiators at the correct conditions.

Figure 1: TPC Group chemical plant explosion in Port Neches, Texas due to a pipe rupture. Process Controllers can prevent plant disasters by detecting and adjusting for disturbances [1].

Theory

Different controller designs vary in how disturbance changes are accounted for due to the different parameters of interest(s) each controller chooses to explore. Equations (1) to (4) relates the parameters governed by each controller to the output.

P Controller: $H = K_c\varepsilon + H_s$ — (1) **PI Controller:** $H = K_c\varepsilon + K_c\tau_D\frac{d\varepsilon}{dt} + H_s$ — (2)

PD Controller: $H = K_c\varepsilon + \frac{K_c}{\tau_I}\int_0^t \varepsilon dt + H_s$ — (3) **PID Controller:** $H = K_c\varepsilon + \frac{K_c}{\tau_I}\int_0^t \varepsilon dt + K_c\tau_D\frac{d\varepsilon}{dt} + H$ — (4)

With the equations pertaining to liquid level process control, **H** is the height of the tank, **Kc** is the proportional constant, **ε** is the difference between the measured height and the set point, **τI** is the integral time constant, **τD** is the derivative time constant and **Hs** is the steady state height of the tank. Out of the 4 controllers, the theoretical assumption is that a ***PID*** controller produces most optimal results due to incorporation of both derivative and integral terms in the controller, allowing the controller to predict future responses based on previous historical data.. Hence, such a controller will experience the ***least overshoot*** and achieved the ***fastest time*** to reach system steady state.

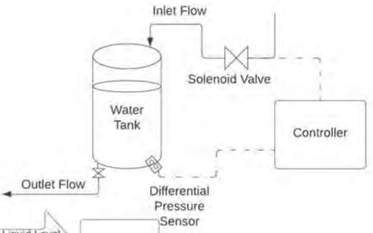
However, additional optimization to controller performance can be implemented in the form of tuning. In this experiment, Ziegler-Nichols (Z-N) tuning was used in a PID controller in an attempt to minimize disturbance rejection. **Figure 2** outlines the tuning rules for the Z-N method. Note that K_u & P_U refer to the *ultimate gain* (min no. of controller gain to sustain oscillation peaks) and *ultimate period* (time between successive oscillation peaks) respectively.

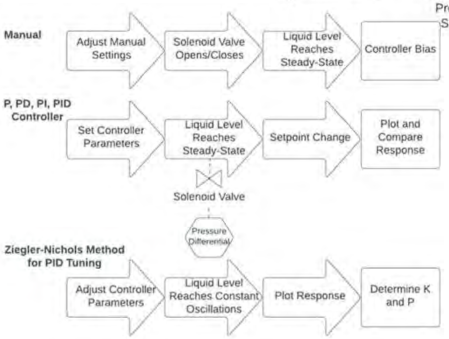
Type of Control	K_c	τ_I	τ_D
Proportional	0.5*K_u		
Prop-Integral	0.45*K_u	P_u/1.2	
Prop-Int-Der	0.6*K_u	P_u/2	P_u/8

Figure 2: Z-N tuning rules [2]

Materials & Methods

A liquid level tank was equipped with 2 input solenoid valves: one partial and one basic. The output flow was controlled by one hand valve (pictured) and 2 solenoid valves which were not used. The tank also had 2 fail safes in place to stop input flow should the water level get too high (not pictured). Finally, the tank was equipped with a differential pressure sensor at the bottom to measure the liquid level at any time.





To compare the response of different types of controllers, first the manual controller bias is determined.

The controller is then switched to automatic and the response of the 4 different controllers is investigated.

Once each controller is tested, the Ziegler-Nichols Tuning Method is used to tune the PID controller and determine the best tuning parameters for the controller.

Finally, as part of the tuning process, the values of Derivative and Integral time are modified to observe their effect on the response

Results & Discussion

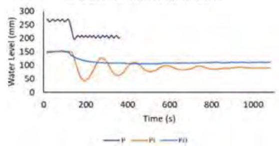
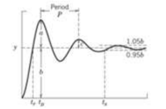
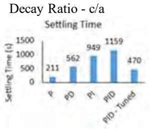


Figure 3 : The figure shows how different controllers react to a sudden set point change

There are different properties that help with characterizing the performance of the controllers. These properties can be obtained by looking at controllers' response graphs and doing some simple calculations. Some of these properties include:

- Rise Time - time process output takes to first reach the new steady-state value
- Time to First Peak - time required for output to reach and remain inside a 5% band of the total change in the output
- Offset - difference between steady state output and input setpoint
- Overshoot - a/b
- Decay Ratio - c/a





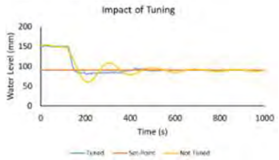


Figure 4: The figure shows the response of non tuned PID and PID that is tuned using Ziegler Nichols method

Table 1: Performance characterization properties for P, PD, PI, PID-Tuned, PID-Not tuned controllers

Properties	P	PD	PI	PID Tuned	PID Not Tuned
Rise Time (s)	NA	170	160	151	264
Overshoot (%)	NA	NA	78	16.7	50
Time to 1st peak (s)	145	NA	195	203	208
Period (s)	16	NA	202	26	189
Decay Ratio	0.9	NA	0.57	0.9	0.37
Settling time (s)	211	562	949	470	1159
Offset (mm)	110	20	0	0	0

These results indicate the following:

- Tuned PID controller showed the best performance because it had one the lowest settling time without an offset nor big oscillations.
- Untuned PID performed worse than PI (higher settling time & large time to 1st peak > slower response). This shows the importance of tuning the PID controller before usage.
- Although P controller had a fast response time, the large offset from the set point makes it undesirable

Design Extension

As engineering students, it seemed wrong to have a fountain that was not properly controlled and regulated. For our design extension we propose a few additions to the famous Infinity Fountain.

Figure 5: UCI's Infinity Fountain overflowing after rain

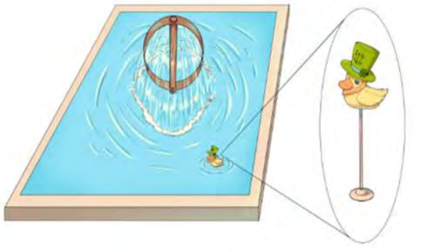


Figure 6: Schematic of new design for fountain

A solenoid valve outfitted at the base of the infinity circle is used to regulate the input flow to the fountain. The valve will be controlled by a tuned PID controller.

To monitor the liquid level, a differential pressure sensor is installed at the bottom of the fountain, near the edge to prevent overflowing and make maintenance easy.

Additionally, due to the gap in the data set, any disturbances outside of a setpoint change may not be well regulated with the experimental controller — a fail safe is required. The sketch above depicts the floating duck decoy with a drain plug attached at the bottom. If the water level gets too high due to rain or another disturbance, the duck will float up and the drain will open. Once the water level decreases, the duck will fall back into place and the drain will be closed.

Unfortunately, data on disturbances, specifically and increased input, was not collected and a more detailed process control loop cannot be designed for the system. Additionally, the infinity fountain is a relative low-risk system so the cost of implementing the process controls would outweigh the benefits.

Conclusion

The experiment investigated the effectiveness of the different process controllers on maintaining the liquid level of a tank that undergoes disturbances. It was hypothesized that a tuned PID controller would be the optimal controller. The liquid level graphs for each type of controller were analyzed to determine its efficiency. The hypothesis is supported by the results, where the Ziegler-Nichols tuned PID controller had the fastest settling time of 470 seconds and no offset, but the untuned PID controller had the slowest settling time of 1159 seconds without offset. PI and PD controllers had moderate settling times of 949 and 0 offset and 562 seconds with 20 mm offset, respectively. The P controller had the fastest settling time, but it had a large offset of 110 mm, indicating that it is nonoptimal as a process controller. Therefore, a tuned PID controller is an ideal process controller and should be implemented to maintain process operating conditions.

To expand upon the experiment, different type of disturbances, such as load changes and environmental changes, can be tested to determine how each process controller responds. Also, the effectiveness of different process controllers on maintaining temperature can be investigated.

References

[1] J. Johnson, "US Chemical Safety Board issues delayed accident reports," Cen.acs.org, 04-Jan-2023. [Online]. Available: https://cen.acs.org/safety/industrial-safety/US-Chemical-Safety-Board-issues/101/web/2023/01. [Accessed: 14-Mar-2023].

[2]. Coughanowr, Donald. Process Systems Analysis and Control. 2nd ed. McGraw Hill, 1991.

[3] Seborg, Dale E. Process Dynamics and Control. JOHN WILEY & Sons, 2019.