Design and implementation of water level control for two coupled tank as a simple and low cost apparatus in automatic control engineering education

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Abstract. The aim of this paper is to design a simple and low cost prototype apparatus for automatic control engineering education. The activities were arranged in order to support the development of student skill, particularly in control design for water level system. The system was developed from many parts such as coupled water tank, water level sensor, flow actuator and microcontroller. The integrated system characteristic was observed in order to understand the dynamics response and design the proper control law. The open loop system was approximated as first order system and has time constant $\tau$ about 7.59 second. The control scheme was designed using the conventional proportional and integral (PI) strategy. The proportional gain and integral gain were derived from dynamic characteristic, resulting 1.96 and 0.25 respectively. The experimental result showed rise time (Tr) 0.06 second, settling time (Ts) 0.17 second and steady state error around 8.55% relative to set point value.

1. Introduction

This paper presents the implementation of simple apparatus in automatic control teaching. Mostly, the material of automatic control lecture covered the system dynamic and the compensation strategy in order to modified the system performance. Those materials tend to be mathematical and abstract. Therefore, it is necessary to present the teaching of automatic control in appropriate implementation and experimental activity. It was expected to help student in understanding of automatic control studies. The control engineering discipline may be said in the border between the various disciplines, there are physics, mathematics, computer science, and communication [1]. So to understand that field, we required the understanding of other supporting science. For instance, in case of controlling the fluid system, the control engineer needs perspective and knowledge from physics science about fluid system characteristic, mathematical modelling, and computation science. Therefore, this paper discussed about comprehensive student activity improvement in studying dynamic of fluid system, transfer function modelling, design and implementation of PI control in microcontroller device, and also analysing the process performance. The activity was realized in student group discussion in order to improve the social interaction, communication skill and teamwork.

The PID control has been extensively implementing in industrial practice [2], that has simple formula and more applicable in widely hardware or devices. The basic PID scheme were developed in parallel structure between proportional, integral and derivative. Particularly in this paper discus about
implementation the PI control scheme and consider to its influence in process error reduction in water level control process.

2. Experimental Methods

2.1. System Description

In this study, we consider that automatic control is not only discussed about control strategy but also needs the dynamic process understanding, therefore the student group discussion focus to define the system structure, learning the process dynamic and experimental characterization as the preliminary activities. The dynamic information would be advanced to found the proper control strategy related to the dynamics characteristic. The system developed into several sub-systems, there were two coupled tank, modified valve with servo motor as a simple flow actuator, water level sensor, microcontroller and water pump. All of sub-systems were integrated into a complete system as shown in Figure 1.

![Figure 1. System integration](image)

The system described with piping structure as shown in Figure 2.

![Figure 2. System and Piping](image)

| Symbol | Definition                  |
|--------|-----------------------------|
| R      | Resistance                  |
| D      | Tank diameter               |
| C      | Capacitance                 |
| h      | Water level                 |
| q      | Water flow                  |
| q₂     | Water level rate            |
| τ      | Time constant               |

Table 1. Symbol

Based on the system structure in Figure 2, the regulated water flow \( q₁ \) drops from reservoir into tank 2

\[
q₁ = C \dot{h}
\]

(1)

that flow will effect the water level \( h₂ \) on tank 2, at the same time its water pressure will make influence the water level \( h₁ \) on tank 1, and output flow \( q₃ \). Consider that water flow \( q₁ \) was not forced flow, its just
influence by gravity and valve opening, in the other hand $C_1$ and $C_2$ are relative big than $q_1$. Based on that, we assume that the change of $h_2$ will changed $h_1$ with slow rate value. The consequences, the system was approximately with first order model as shown in Equation (2).

$$G(s) = \frac{h_1}{h_2}(s) = \frac{1}{(ts + 1)}$$  \hspace{1cm} (2)

The time constant ($\tau$) is the time required to achieve 63% of the final value. In this case that value was obtained from response curve that collect from water level output characterization. The time constant value is about 7.59 seconds.

### 2.2. Control Design

The control design was used proportional integral control and performed by an output feedback mechanism as shown in Figure 3. The PI control expected to pursue the set point value $h_1$ with lowest error. There were two parameters should be determined, there are proportional gain ($K_p$) and integral gain ($K_i$).

![Figure 3. Block Diagram](image)

The transfer function for close loop $G_{cl}(s)$ are as follow

$$G_{cl}(s) = \frac{G_p(s)G(s)}{1 + G_p(s)G(s)}$$  \hspace{1cm} (3)

transfer function for PI control

$$Gpi (s) = Kp\left(1 + \frac{1}{\tau_i s}\right)$$  \hspace{1cm} (4)

and transfer function for process $G(s)$

$$G(s) = \frac{k}{(ts + 1)}$$  \hspace{1cm} (5)

The integral time was stated equal to process time constant $\tau_i = \tau$ so the close loop equation becomes

$$G_{cl}(s) = \frac{1}{(K_p K_i) s + 1}$$  \hspace{1cm} (6)

From equation 6, the value of $\tau_{cl}$ depends on the values of $\tau$, $K_p$, and $K$. If the close loop performance speed up about $\alpha$ times faster, then $\tau_{cl} \approx \alpha \tau$. In this experiment the system wants to be accelerated faster from the original process, then we chose the value $\alpha$ about 0.5 so that

$$\tau_{cl} = \frac{\tau}{K_p K_i}, \text{if } \tau_{cl} = 0.5\tau \text{ and } K = 1$$  \hspace{1cm} (7)

$$Ki = \frac{K_p}{\tau_i}, \text{if } \tau_i = \tau$$  \hspace{1cm} (8)

Then we obtained the value of proportional gain $K_p$ about 1.96 and integral gain $K_i$ approximately about 0.25.
3. Result and Discussion
The system was observed in time domain characteristic both transient and steady state. The experiment results are shown in Figure below with water level reference 6 cm and utilizing the control parameter values, proportional gain Kp and integral gain Ki discussed earlier. The implementation result shows no significant overshoot, however it has small fluctuation and may caused by water ripple. Rise time Tr was observed abut time respond that required to react from the point 10% to 90% that is 49 seconds. Meanwhile, the settling time Ts was measured of time that states the response has entered about 5% of the steady state value, so time selection associated with error generated system with the value of Ts around 1.67 minutes.

4. Conclusion
The control strategy determination is essential in process engineering, it will influence the characteristic and performance of the system. In automatic control learning, it is necessary to instill an understanding of system dynamics, comprehensive control and computational design. During observation activities, it appears that students were better trained in applying the concept of control in case studies, it is expected
to be able to support the formation of better motivation, basic knowledge and skills in an integrated manner. Problem solving approach through study groups is also important, this is also an opportunity to instill the student abilities in communicating, team working, and practicing professionalism.

5. References

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