

Design of a Height Control System for Folsom Dam

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Abstract— This system presents the water control system of the Folsom Dam in California. The water level is required to be under 60% of the dam's height. By collecting the previous year's data, and using a centered moving average for data cleansing, we were able to estimate the amount of water being introduced to the reservoir from precipitation and other water bodies. By using *SIMULINK* and applying a proportional control to the system we were able to handle the water level inside the dam. To determine the proportional control a root-locus plot was created and analyzed, giving us outstanding results, where the system is able to reach and maintain the desired water level depending on the initial conditions.

Keywords: reservoir, root-locus, proportional control, centered moving average

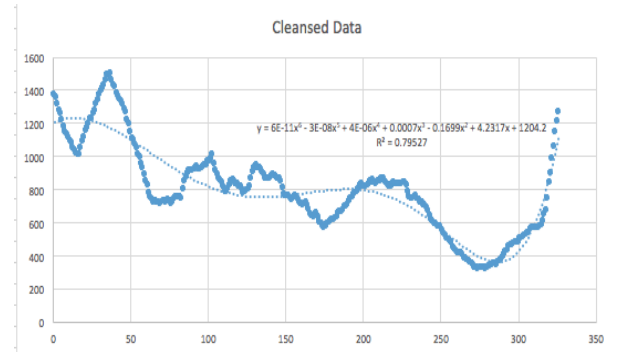
I. INTRODUCTION

There is a continuous increase in population surrounding dams which creates the need for systems that ensure and comply with dam regulations and requirements [5]. The purpose of this research project is to model hydroelectric dams and the uninterrupted monitoring of its water levels. Using the Folsom Lake Dam as the case study of the project, data was gathered in order to derive equations used to model its behavior, while complying with the current laws and regulations.

II. METHODOLOGY

A. Data Cleansing

The data used to model the inflow of water entering the reservoir was collected from the California Data Exchange Center. Given the nature of the data, extensive cleansing had to be performed. A centered moving average was used to cleanse the data, and a polynomial regression was performed providing a $r^2 = .79527$. This polynomial will be used as the input of our system.



B. SIMULINK

Simulink was used to model this system. The input was constructed by the data provided by California's Water Department. An integrator block is used to determine the actual water level. Resistance is affected by the change of height. A summer block was used to calculate the error in height by computing the target height given by the step function minus the actual height, which is then multiplied by the gain block K. The switch block triggers the resistor--if the error is negative, the actual height is larger than the target, meaning water has to come out to bring the height down to the target height. 9.81 gain blocks are used to multiply the value of gravity. Area is 48,278,997 m².

C. MATLAB

MATLAB was used to retrieve a root-locus plot, from it an optimal constant for the proportional control block was obtained.

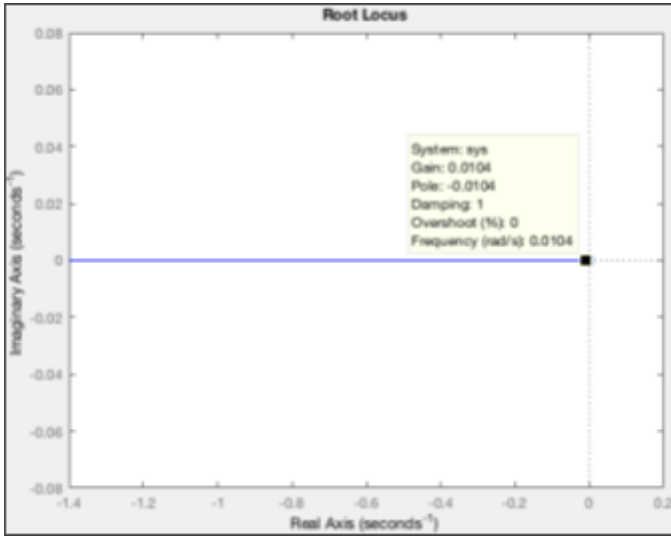
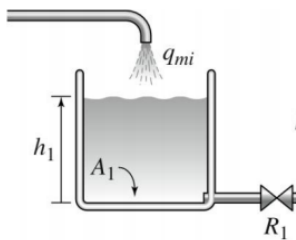


Figure 1. Root Locus Plot

D. Units

- m = mass (kg)
- g = gravity ($\frac{m}{s^2}$)
- h = height (m)
- P = pressure (Pa)
- V = volume (m^3)
- q_{mi} = inflow ($\frac{kg}{s}$)
- R = resistance (Ω)
- ρ = density ($\frac{kg}{m^3}$)
- A = area (m^2)
- R_{ss} = steady- state resistance (Ω)

E. Equations



Equation (1) represents the density of the water and (2) represents the volume of the container holding the water. We then solved for m , which is shown in equation (3). We solved for m so we could take the derivative of it and get the mass flow, which is represented by

equation (4). Mass flow can also be defined as the conservation of mass (equation (5)), which is the quantity going into the container subtracted by the amount of water leaving the system over time. Equation (6) illustrates the flow resistance. Due to q_1 being an intermediate variable, we solved for q_1 , (equation (7))

and substituted it into equation (5), which gave us equation (8). Equation (9) represents the resistance at steady state, which was determined by setting equation (8) to zero and then solving for R .

$$(1) \rho = \frac{m}{V}$$

$$(2) V = A * h$$

$$(3) m = \rho * A * h$$

$$(4) \dot{m} = \rho * A * \dot{h}$$

$$(5) \dot{m} = q_{mi} - q_1$$

$$(6) P_1 - P_2 = q_1 * R$$

$$(7) q_1 = \frac{P_1 - P_2}{R}$$

$$(8) \rho * A * \dot{h} = q_{mi} - \frac{\rho * g * h}{R}$$

$$(9) R_{ss} = \frac{\rho * g * h}{q_{mi}}$$

III. RESULTS

The steady state height achieved by our model comes out to be our target height. When the initial height is below the target height (Figure 3 & 4), the system stays idle for a period of time and a sharp increase is observed when it hits a certain point. When the system's initial height is above the target height (Figure 2) the same behavior is evidenced, where we see a period of inactivity and a sudden decrease. Since the initial height is larger than the target height, rather than rising, the amount of water slowly decreases. The system's time to steady state is proportional to the initial height of the system, the farther away from the target height the longer it takes to reach steady state. In the end, this makes sense because when thinking of it abstractly, if a container is almost full it wouldn't take much time to fill it to its full capacity.

The effect of a non-optimal proportional control value ($K = 0.21$) was studied and graphed (Figure 5). A higher oscillatory error is observed compared to the optimal proportional control value ($K=0.00001$)(Figure 7). When the proportional control value is changed to a gain of 0.3 it causes the system to become unstable and to increase without bound (Figure 6).

IV. Conclusion

The goal of our system was to adjust the water level of a dam in order to keep it at 60% of its capacity. Our system works efficiently, which is proven by our final simulation where no oscillatory error was observed. Moreover, our system reaches steady state at the target height regardless whether the input value is less than or greater than the target value.

Our model has different limitations such as the response to different types of inputs. If the system were to get an input that increases without bound, which is an unrealistic assumption, our system would become unstable.

Overall the system model is robust and behaves adequately when realistic inputs and used to test it.

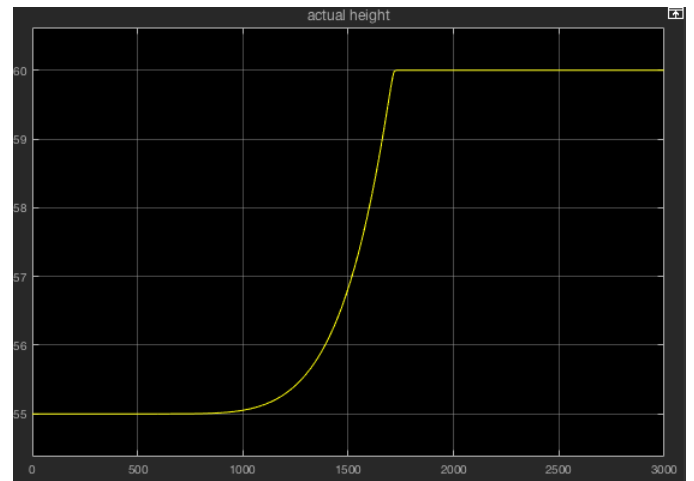


Figure 4. Faster increase to steady state from initial height of 55m.

V.

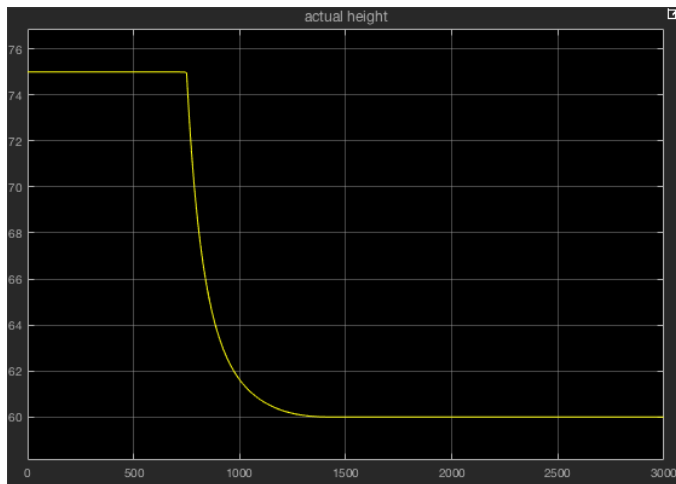


Figure 2. Slow decrease to steady state from initial height of 75m.

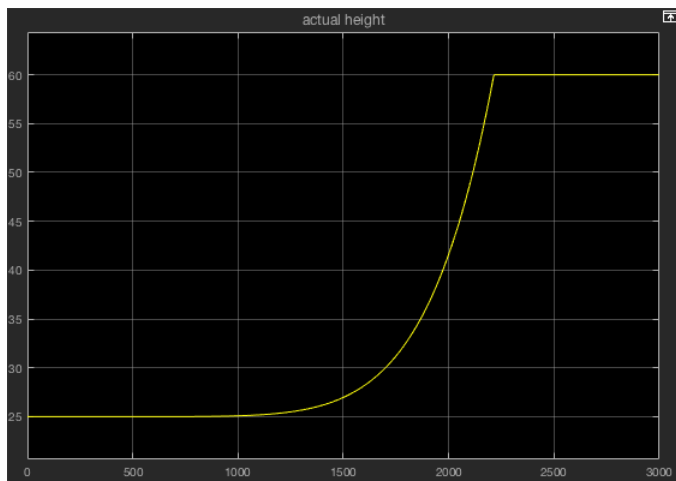


Figure 3. Slow increase to steady state from initial height of 25m.

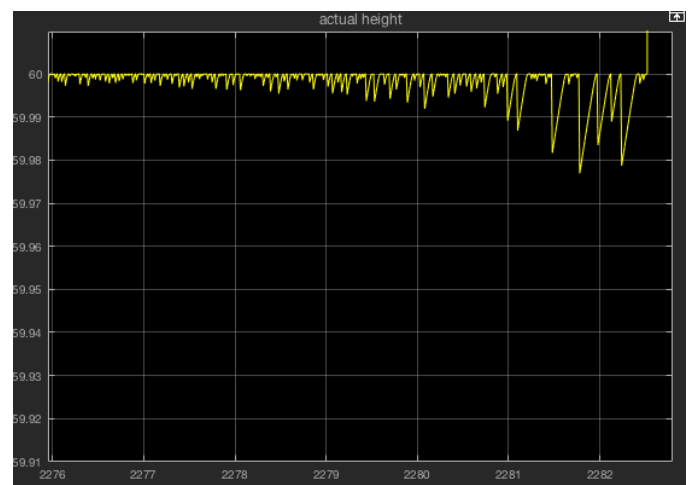


Figure 5. At a proportional control gain of 0.21 the system oscillates at steady state before continuously rising.

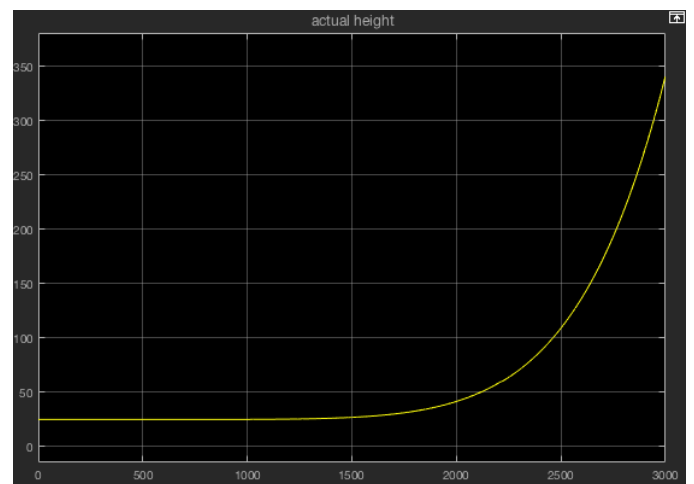


Figure 6. The model's behavior increases exponentially with a proportional control $k = 0.3$

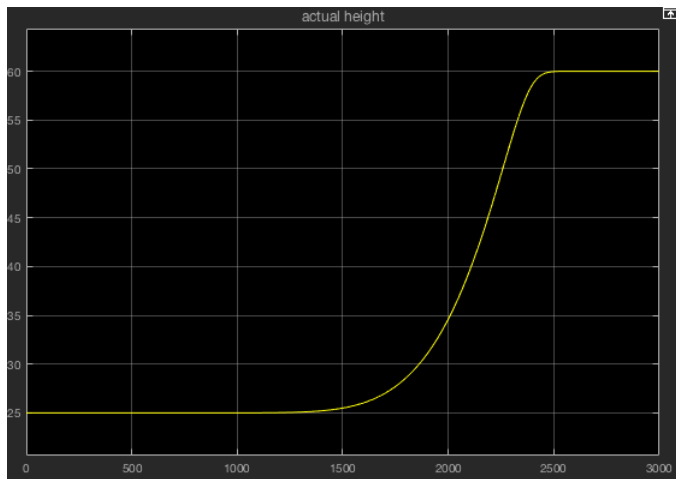


Figure 7. The model transitions much smoother to steady state with a proportional control of 0.00001

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Shallu Darhele is pursuing her B.S. in Systems Engineering with a technical emphasis in Operations Research and a minor in Aviation Flight Training and Management. She serves as a member of GMU's INCOSE Student Chapter. Shallu is a professional aviation flight service provider gaining her experience through attending flights for major commercial airlines such as US Airways and American Airlines. Her current research interests are operations research, optimization, air traffic and airport operations.

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