Full state feedback and feed forward control of servo smart window using MATLAB/Simulink

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ABSTRACT

House as a place to carry out daily activities requires healthy air. The right step to improve air circulation is to use smart window. A control system method is needed so that smart windows can automate air circulation better. Temperature sensor will determine the minimum, maximum, and opening size of the smart window in order to perform the function of opening and closing effectively. Servo motors are used as actuators in the process of opening-closing windows. In this research, the full state feedback and feed forward control method are used to determine the best control theory for servo motor control for smart window systems. The motor control system modeling in smart window is designed by applying the previously studied control theory. Mathematical modeling was carried out to obtain system equations and performance index. The equation is then applied to the MATLAB/Simulink simulation so that the stability of the system can be monitored against disturbances in the form of noise originating from the sensor or the control system itself.

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1. INTRODUCTION

A healthy environment will greatly affect the physical health of living things. Air contains oxygen that living things need for respiration and metabolic processes of the body. But in addition to oxygen, there are other compounds such as carbon dioxide, carbon monoxide, hydrogen, nitrogen, viruses, dust, and others. Arulmozhiyal and Baskaran [1] certain levels, these substances can be neutralized by the body, but if it crosses normal limits it will interfere with health. The indirect impacts include lung disease, heart disease, and cancer. This impact is caused by continuous exposure over a long period of time, so indirect effect is very difficult to treat [2].

Good air quality is important for every home to have. The right step to improve the air content in the house is to install equipment that helps to improve air circulation. One of the important equipment that can help condition of the air content in the house is window [3]. The window serves to open space between air inside and outside the house in order to be able to exchange air. However, due to human capacity and time limitations, it is difficult to manually detect and perform actions against existing facilities. Therefore, it takes an automatic capability that can control the equipment to be able to adjust its actions according to the air conditions in the house at that time [4].

This study implemented a three-parameter room air quality monitoring system, namely temperature, humidity, and carbon monoxide levels and used sansevieria plants to see how it affects the room's air quality [5]. The system will be used to analyze air quality by comparing several controls to open windows that serve to stabilize the temperature of the room [6]. This paper aims to design a control system simulation for smart windows in the process of monitoring air quality to be better in smart building research in order to be applied in the room. With this research, it is expected to help human work in monitoring air quality [7]. In addition, it can improve the air quality in room through equipment that is already in the room.

2. METHOD

2.1. Electrical model characteristic

Figure 1 shows the freebody diagram of armature of a direct current (DC) servo motor. Freebody diagram shown a diagrammatic representation of a single body or subsystem of body isolated from its surroundings showing all the forces acting on it [8]. Referring to Figure 1, the torque develop is directly proportional to the armature current $i_a$as shown in (1), when $K_t$is motor torque constant. The eb is back-electric motive force voltage, which induced in armature winding [9]. While θ_m is angular.

$$T_m \propto \omega_f i_a,\ T_m = K_t i_a \tag{1}$$

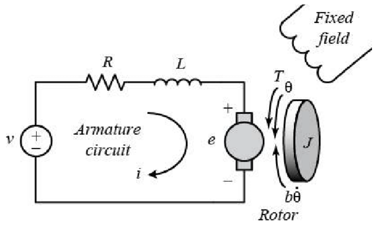

Figure 1. Freebody diagram of armature of a dc servo motor

2.2. Servo motor actuator parameters

There are several parameters of servo motor actuators. Therse parameters relate to the things needed for system measurement. According to the inertia and damping the torque produces an angular velocity, the differential equation of torque motor showed in (2).

$$J_m \frac{d\omega_m}{dt} + b_m \frac{d\theta_m}{dt} = T_m = K_t i_a \tag{2}$$

Where J_m is inertia, θ_m is motor angular displacement, ω_m is motor shaft angular speed, b_m is damping friction, i_a is armature current, K_t is motor torque constant. This formula is used to make simpler equations. Table 1 shown configuration parameters of servo motor [10].

Table 1. Configuration parameters of the system

Parameters	Values
Momen of inertia rotor (J)	1.2x10^{-6} (kg-m$^{2)}$
Damping ratio (b)	6.71x10^{-6} (Nms/rad)
Torque constant (K)	0.015 (Nm/amp)
Electric resistance (R)	2.02 (ohm0

2.3. State space modelling

For the state space model, we take Laplace of (3) and (4).

$$U_{in}(s) = L\ _a s I_a(s) + R_a I_a(s) + K_b s\theta_m(s),\ i_a, K_t, T_m \alpha\omega \tag{3}$$

The Laplace function become:

$$J_m s^2 \theta_m(s) + b_m s\theta_m(s) = K_t i_a(s) \tag{4}$$

if L_a neglected a , the $K_t = K_b = K$, and (5).

$$\frac{\theta_m(s)}{U_{in}(s)} = \frac{\frac{K}{R_aJm}}{s^2+s\left[\frac{R_ab_m+K^2}{R_aJm}\right]} \quad (5)$$

Then take the inverse Laplace transform of (5).

$$\theta_m^{"} = -\left(\frac{R_ab_m+K^2}{R_aJ_m}\right)\theta_m^{'} + \frac{K}{R_aJ_m}U_{in} \quad (6)$$

Assume the state variables and from (6).

$$\begin{bmatrix} x_1^{'} \\ x_2^{'} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & -\left(\frac{R_ab_m+K^2}{R_aJ_m}\right) \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{K}{R_aJ_m} \end{bmatrix} U_{in} \quad (7)$$

$$y = \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} \quad (8)$$

The determine A, B, C, and D constanst for the state space (9).

$$A = \begin{bmatrix} 0 & 1 \\ 0 & -\left(\frac{R_ab_m+K^2}{R_aJ_m}\right) \end{bmatrix}, B = \begin{bmatrix} 0 \\ \frac{K}{R_aJ_m} \end{bmatrix}, C = \begin{bmatrix} 1 & 0 \end{bmatrix} \quad (9)$$

2.4. Full state feedback controller

Feedback control consists of sensors and/or transducers that are useful for physical value meters related to the control system, and are converted into voltage and current signals [11]. On the basis of the controller is used to compare the actual value of c(t) (output), with the reference value r(t) (setpoint) so that the error value r(t) is obtained, and will get an input signal on plant u(t) that can make the plant has an error value close to zero [12]. Figure 2 shows a block diagram of a control system problem with a controller in a time domain with step input.

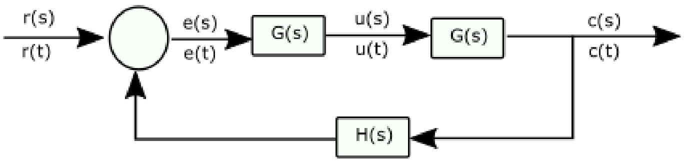

Figure 2. Time domain block diagram of problem system control

Error in a system can change based on time by utilizing this controller designed to be able to predict the next value of the error signal. This is making this error also can provide an appropriate response [13]. These controllers are designed to follow the shape of the (11).

$$u = -Kx \quad (11)$$

Gain K value in the equation above is selected in such a way that the eigenvalue can be placed at the desired value [14]. Here is a simple design of the state feedback controller. For the DC state space gain equation in discrete form with function transfer value at frequency s=0, with matrix shape (A, B, C, D) as shown in the (12). DC gain has unlimited value on systems with integrators [15]. One of the advantages of this system is the ability to accelerate settling time (Ts), rise time (Tr) and percentage overshoot (%Os) of the system.

$$K = D - C(I - A)^{-1}B \quad (12)$$

2.5. Feed forward controller

This controller works by reducing the steady state error to zero for input on the plant [16]. The initial of the state feedback controller was made to make A-BK stable. Supporsing r(t) the reference input, the steady state vector will be associated with the (13), where $x_{ss} = N_x r$ for each r input constant [17].

$$u = -K(x - x_{ss}) + u_{ss} \tag{13}$$

Where the equation u_{ss} can be express as in (14).

$$u_{ss} = N_u r \tag{14}$$

For all command input *r*, N_u, and N_x are now written as (15).

$$\begin{bmatrix} N_x \\ N_u \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}^{-1} = \begin{bmatrix} 0 \\ 1 \end{bmatrix} \tag{15}$$

The control law can be written as (16):

$$u = -K(x - N_x r) + N_u r, u = -Kx + Nr \tag{16}$$

where N (17):

$$N = N_u + KN_x \tag{17}$$

3. RESULT AND DISCUSSION

This section will talk about the simulation results of the three different controllers from each other. The simulation was conducted using MATLAB/Simulink software. The results of the simulation will be displayed in the form of a table as a performance comparison medium. The following specifications are being set for simulations to compare the control parameters for two different controllers. Following Figures 3 and 4 shows the MATLAB/Simulink simulation for full state feedback adding integral action and feed forward controller without adding disturbance.

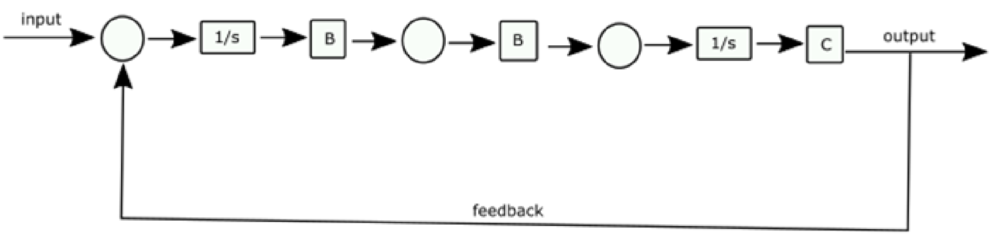

Figure 3. Block diagram of full state feedback controller adding integral action

The simulation result of Figure 3 as the response of the system with full state feedback controller adding integral action. Because the feed forward controller (FFC) is made with specifications to eliminate the disturbance so that the results of system response will only be displayed in the comparison of the system response to the disturbance [18]. The disturbance given affects the result of response system.

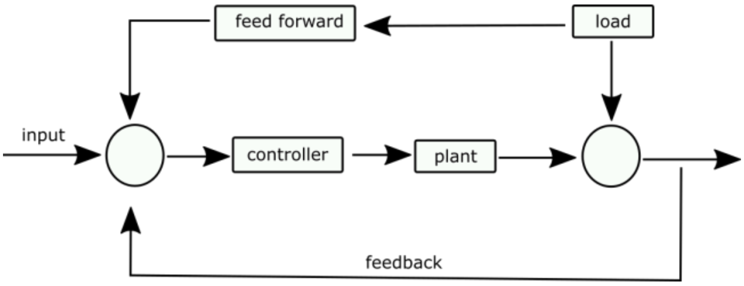

Figure 4. Block diagram of feed forward controller

The simulation result of Figure 4 as the response of the system with feed forward controller. From the result, we can analyze the best response system for servo motor system without disturbance added. We can analyze that from the response system parameter such as settling time, rise time, peak time, percentage of overshoot, and steady state error [19].

Figure 5 shows full state feedback adding integral action control system response without the addition of disturbance. From the response system it shows a graph that experienced a considerable overshoot [20]. The overshoot occurs for a while until the system finally reaches a steady state condition.

Then add the disturbance at input side of the proportional integral derivative (PID), full state feedback, and feed forward controller in Figure 6 [21]. Disturbance given is symbolized by gain disturbance (GD) is $\frac{5}{2s^2+s}$. Then analyze the performance of the controller under noise induced condition at input side which simulation model is shown is Figures 7 to 10.

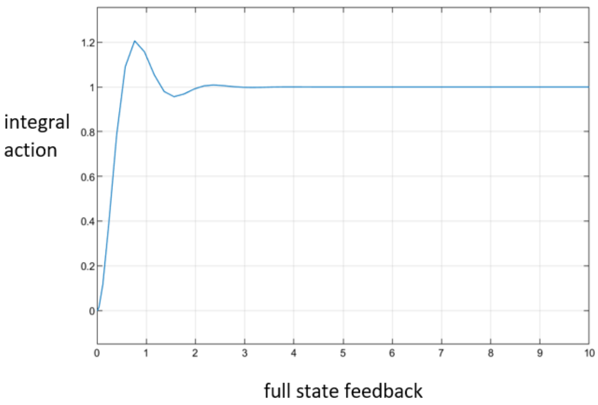

Figure 5. Simulation result of full state feedback controller

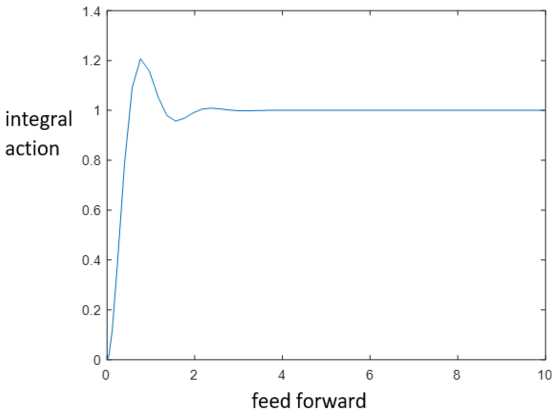

Figure 6. Simulation result of feed forward controller

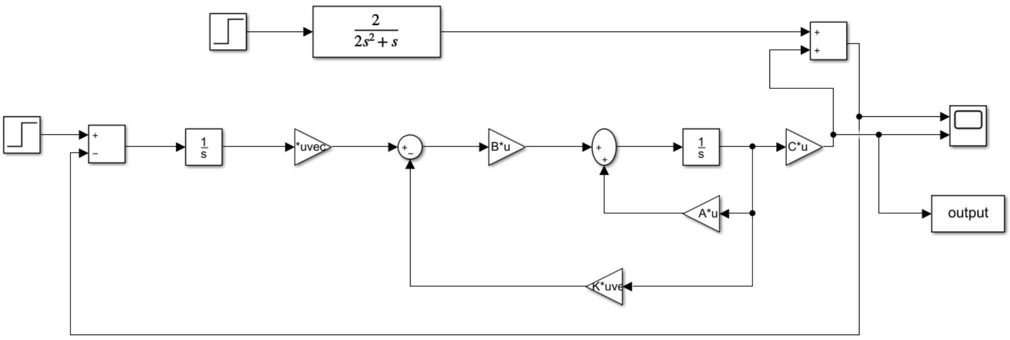

Figure 7. Full state feedback adding integral action controller with disturbance

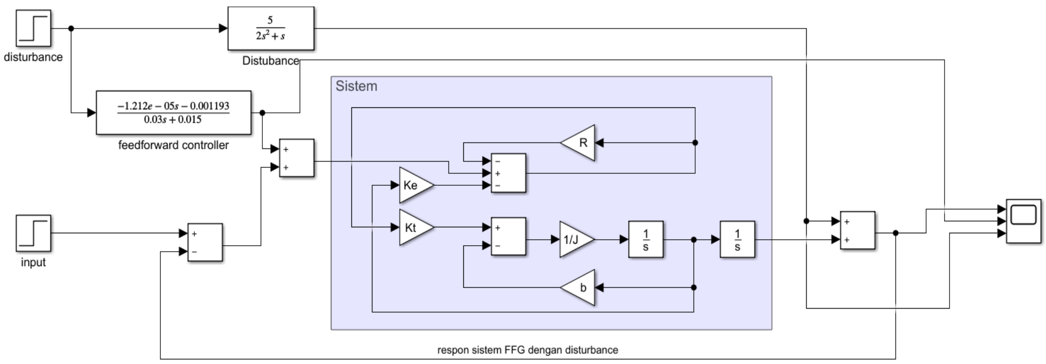

Figure 8. Feed forward controller with disturbance

Figure 7 shows that full state feedback adding integral action controller with disturbance are using some add, integrator and comparator components with logic [22]. The input given is a step input signal with the same disturbance equation as before. In addition, the PID control signal input is also given which then goes to the same integrator as the disturbance input.

Figure 8 shows that feed forward controller with disturbance using more integrator, add, and a transfer function component on Simulink. The own system are using gain Ke and Kt [23]. It also use feedback R and b. The result of simulation Figures 7 and 8 shown in Figures 9 and 10.

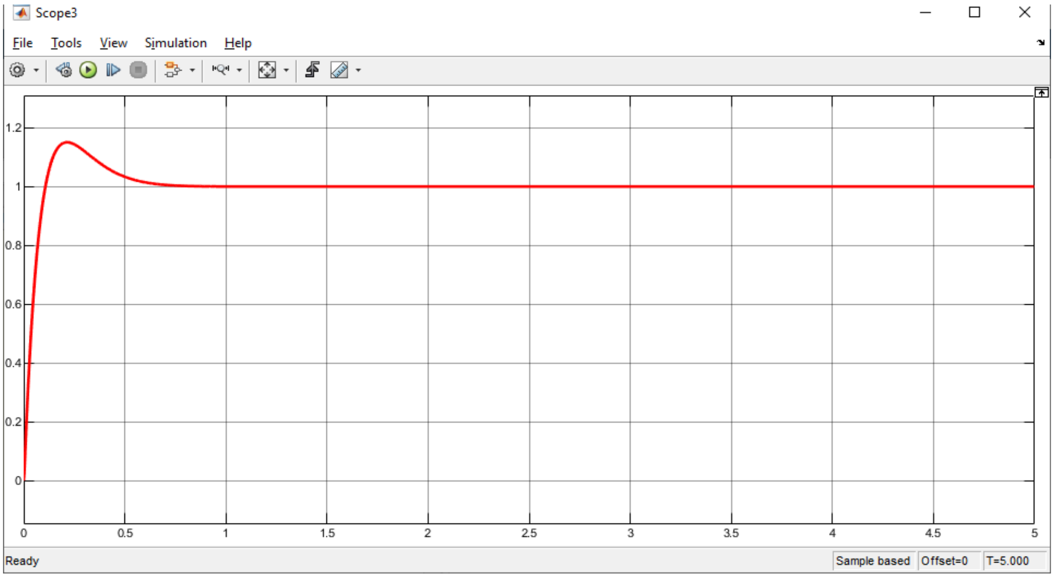

Figure 9. Simulation result of full state feedback controller adding integral action with disturbance

The result of system response shows that the system response given the addition of disturbance has been close to steady state compared to the system response result of matrix C. The overshoot occurs in less than 1 second. However, it appears that there is still a steady state error from the output of the system after the addition of disturbance [24].

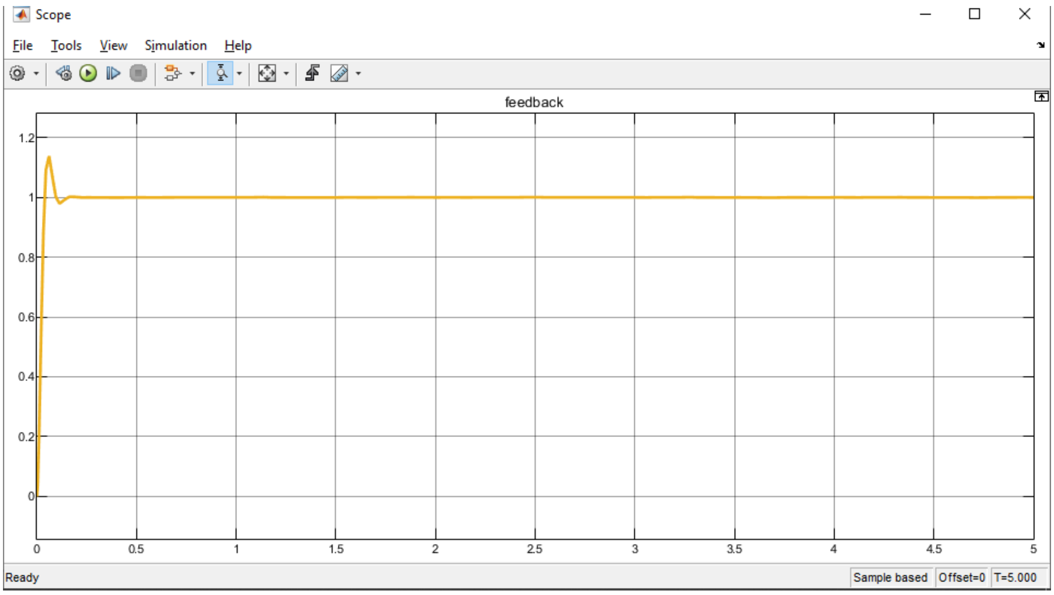

Figure 10. Simulation result of feed forward controller with disturbance

Based on the results of simulations on Simulink with the system that has been given disturbance, the steady state error can be eliminated by using the control of the feed forward controller on the system [25]. The simulation result for case study is shown in Figures 9 and 10. Then, Table 2 shows for its performance.

Table 2. Respon system characteristic

Controller	Input reference	Steady state error	Peak time (ms)	Settling time (ms)	Rise time (ms)	Overshoot (%)
Full state feedback	5	0.1	5	3.5796	1.8921	1.8921
Feed forward controller	5	0	0.0619	0.1143	0.0271	0.0271

From Table 2, it can be seen that the output response for simulation result of study is obtained with absolute discrepancy of 1.1% for percentage maximum overshoot. It also need only 0.1 s to reach the settling time. However, the output response of feed forward controller exhibits very large percentage steady state error [26].

4. CONCLUSION

Mathematical modeling is made to design control circuits in MATLAB/Simulink software. Modeling is made using three types of control, namely PID with Ziegler-Nichols method, full state feedback with pole placement method, and full state feedback with feed forward gain. From the result without disturbance, the PID, full state feedback, and feed forward controller have a good step response. After added disturbance, PID controller has a large steady state error while full state feedback has smaller steady state error. Feed forward controller has the best response system with zero steady state error. It has also validated that feed forward controller with state feedback performs better when there is some noise introduced.

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