ISSN 2355-3286

State-Feedback Control Design for the Cannon Stability System on Tank

Ahmad Syahril Muharom
Electrical Engineering, Universitas Multimedia Nusantara, Tangerang, Indonesia
ahmad.syahril@umn.ac.id

Accepted on 14 June 2023
Approved on 30 June 2023

***Abstract*— Tanks have an important role in protecting a region in the event of a battle. The tank's cannon is a very reliable weapon in warfare. However, the cannon's precision while aiming and firing targets is a concern. A control system must be created to increase the cannon's stability and precision. The state feedback control technique with a full-state observer is the control system that can manage cannon disturbances. The control system is built around three DC motors, each of which operates the cannon's x, y, and z axes. Then performed tests for each axis at an angle of 90 degrees, The state feedback control with a full state observer can produce outstanding performance, with the time required for the cannon to reach the target angle was 0.51 seconds, and the cannon system had 0% overshoot.**

***Index Terms*—Cannon; Full-state Observer; State Feedback Control; Tank.**

I. INTRODUCTION

A country needs military vehicles that are used as instruments to protect or destroy threats [1][2], The main weapon of the tank will be unstable as it tries to cross different heights. Stability is something that must be considered, the cannon must be stable so that the tank can shoot its target accurately [3].

PID control is a traditional control method, is one of many that can be used to stabilize a cannon tank. This traditional control mechanism works well to control oscillations in the system and can be utilized for stability [4].

This system also has many problems, such as being non-linear, poorly actuated, and complex. To improve system performance, researchers are interested in creating this system. State feedback controllers are one of the control strategies utilized to manage this tank cannon system [5]. To describe all states in the cannon tank system, a state feedback controller is not sufficient [6]. To know every state in this system, a state observer must be added [7]. In this study, state feedback control with a full-state observer is used to regulate the cannon tank system. By determining the desired pole, the full-state observer parameter and gain observer are added using the pole placement method. The decision is taken in order to achieve the best reaction with the least amount of control signal..

II. SYSTEM MODELLING

A. Transfer Function DC Servo Motor

This research on the cannon tank aims to control the entire position of the cannon, the actuator uses DC servo motors for each x, y and z-axis [8]. The design of the cannon tank shown in Fig. 1.

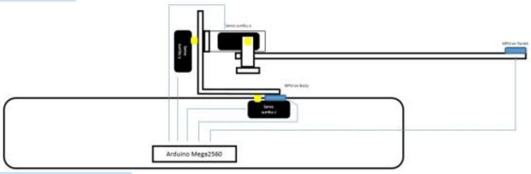

Figure 1. Design of Cannon Tank

The equivalent DC servo motor circuit can be seen in Fig. 2.

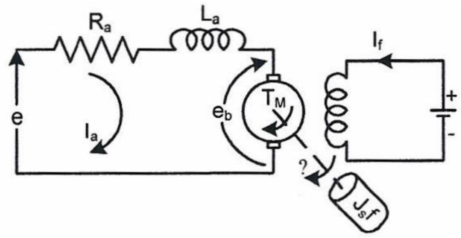

Figure 2. Equivalent Circuit of DC Servo Motor

The transfer function of the servo system can be written as:

$$\frac{\theta(s)}{Ea(s)} = \frac{Ktn}{s[LaJs^2+(Laf+RaJ)s+Raf+KtnKb]} \quad (1)$$

Where,
Ra = Armature Resistor (2.5 Ω)
La = Armature Inductance (0.062 H)
Ia = Armature Current
Va = Applied Armature Voltage
τ = Motor Torque
J = Motor Moment of Inertia (0.00004 Kg/m^2)
Ktn = Motor torque constant 0.026 (Nm/A)
Kb = Back EMF Constant 0.02 ($v.s/rad$)

Considering the value of the gear ratio and the torque of each servo [9], the torque equation for the servo is:

$$T_{total} = (T_m \times n) + t_{disturbance} \quad (2)$$

where n is the gear ratio. Then the block diagram changes to:

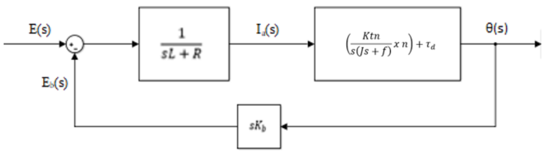

Figure 3. Servo Block Diagram with Gear Ratio and Torque Disturbance

Using the block diagram in Fig. 3, the transfer function for servo x, servo y, and servo z is found:

$$TF_{\text{servo x}} = \frac{0.000003234s^2+0.00008085s+0.117}{0.000002545s^3+0.0001636s^2+0.00484s} \quad (3)$$

$$TF_{\text{servo y}} = \frac{0.0000008154s^2+0.00002038s+0.117}{0.000002486s^3+0.0001624s^2+0.00484s} \quad (4)$$

$$TF_{\text{servo z}} = \frac{0.000005272s^2+0.0001318s+0.117}{0.000002585s^3+0.0001646s^2+0.00484s} \quad (5)$$

B. State Space Representation

The system is shown in a state space model in Figure 4.

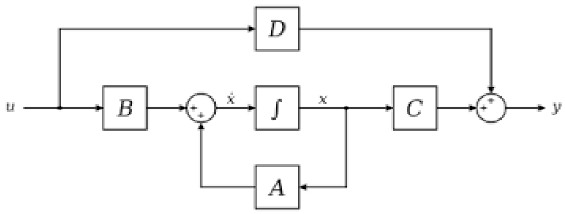

Figure 4. Open-Loop System Representation In State Space

The representatives of the state space equation can be derived as [10].

$$x = Ax + Bu \quad (6)$$

$$y = Cx + Du \quad (7)$$

Determine all coefficients in the numerator and denominator of a transfer function by expanding it [11]. This should result in the following form:

$$G(s) = \frac{n_1 s^3+n_2 s^2+n_3 s+n_4}{s^4+d_1 s^3+d_2 s^2+d_3 s+d_4} \quad (8)$$

The following method can now be used to directly insert the coefficients into the state-space model [12]:

$$\dot{x}(t) = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ -d_4 & -d_3 & -d_2 & -d_1 \end{bmatrix} x(t) + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} u(t)$$

$$y(t) = [n_4 \quad n_3 \quad n_2 \quad n_1] x(t)$$

.

III. State Feedback Control Design

A. State Feedback Controller

A state feedback control system can be seen in Fig. 5 as a diagram. The closed-loop eigenvalues are placed at the desired location using the feedback gain K in state feedback control. To get the output of the system to track the target location despite disturbances is the goal of the feedback control [13].

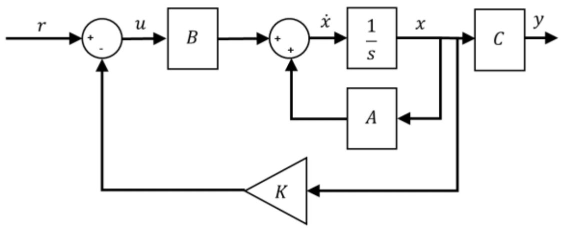

Figure 5. Closed-loop in State Space

The state feedback control system's dynamic equation is obtained.

$$\dot{x} = (A - BK)x + Bu \quad (9)$$

$$y = Cx \quad (10)$$

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

Before implementing the controller, the system model must be analyzed for controllability and observability. The system is controllable if and only if the controllability matrix in Equation (12) has rank=n, where n is the size of the system order [14].

$$C = [B|AB|A^2B| \dots |A^{j-1}B] \quad (12)$$

Equation (13) is the observability matrix, and the system is observable if and only if the matrix has rank=n.

$$O = [C|CA|CA^2| \dots |CA^{j-1}] \quad (13)$$

The closed loop's transfer function H(s) has a gain N, 0<N<1, for a unit-step reference input. The closed loop system in Fig. 4 is shown with a transfer function and is given as:

$$H(s) = C\left(sI - (A - BK)\right)^{-1} B \quad (14)$$

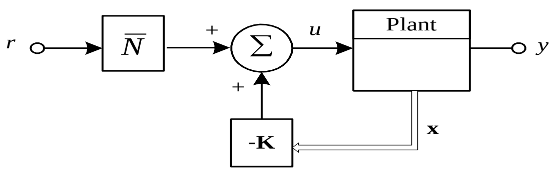

Figure 6. Closed-loop system with gain

The equation of state space can be derived as follow:

$$\dot{x} = (A - BK)x + Bu \quad (15)$$

$$y = Cx \quad (16)$$

$$u = r\bar{N} - Kx$$

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

$$\overline{N} = N_u - KN_x \qquad (17)$$

B. Controller Design by Pole Placement

A technique based on complete state feedback control is the pole placement, as shown in Fig. 5. The denominator of the closed-loop system in Fig. 4 can be determined using the Laplace transfer function [15]. The control gain K can be found by minimizing the performance function.

$$D(s) = sI - (A - BK) \qquad (18)$$

I is the identity matrix in this case. As a result, all of the eigenvalues of **(A-BK)** can be used to assess the stability and transient response characteristics of the closed-loop system. The decision to use a feedback gain design is an attempt to K such that the eigenvalues of **(A-BK)** have negative real values [16].

C. Full State Observer

The observer has a few ways to derive its equation of state from the actual equations of the system, which are in the form of Equations (6) and (7). The full-state observer is shown in Fig. 7.

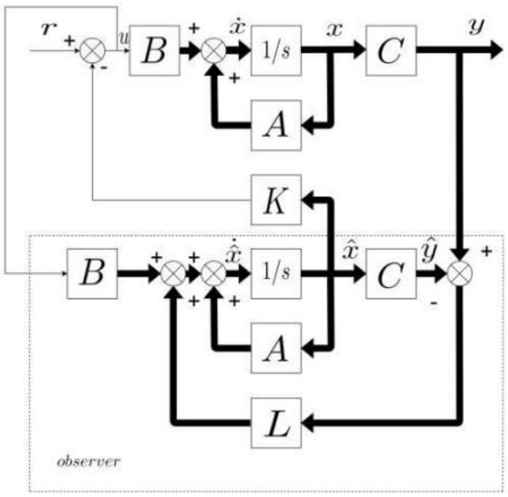

Figure 7. Closed-loop system with Full-State Observer

The gain observer is represented by Equation (18), where L is a n x m matrix. With the original state **x(t)** substituted by the estimate **x̂(t)** and the difference between the actual measured output **y(t)** and the estimate **ŷ(t)**, respectively, the state equations in Equations (18) and (19) model the true equations of the system [17].

$$\dot{\hat{x}} = A\hat{x} + Bu + L(y - \hat{y}) \qquad (19)$$

$$\hat{y} = C\hat{x} \qquad (20)$$

Substituting the equation **ŷ(t)** into the state equation of the observer will result in an alternative form for the model observer as in Equation (20).

$$\dot{\hat{x}} = (Ax + Bu) - \left(A\hat{x} + Bu + L(Cx - C\hat{x})\right) \qquad (21)$$

IV. Results and Discussion

A. Controller Specifications

In this research, it is desired that the maximum overshoot be below 5% and the maximum rise time be 1 second. From these parameters, the values of **ωn** and ζ are obtained as 1.8 and 0.7, respectively. Then, to determine the control pole, see Fig. 8.

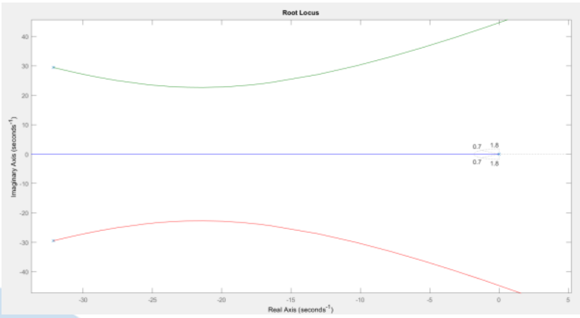

Figure 8. Root Locus Diagram of An Uncompensated System

In Fig. 9, there are values of ζ and **ωn** in the uncontrolled system. To determine the pole placement based on the specifications, the poles need to be placed inside the angle formed from the imaginary axis 0.7 (inside the sloping line of approximately 45 degrees) to realize the specification of overshoot below 5%. To realize a rise time of less than 1 second, the poles should be placed outside the half circle around 0.7 and 1.8.

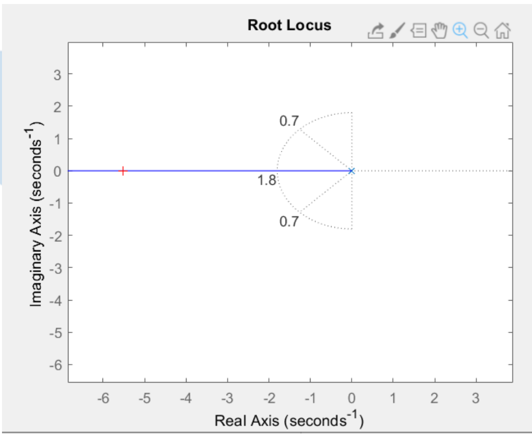

Figure 9. Pole Placement Control In The Root Locus

B. Observer Specifications

The observer desired to estimate ten times faster. Therefore, the pole location of the observer has a value ten times that of the controller's poles. Using equation (20), the gain of the observer is obtained as follows:

L1= 107.06

L2= 3.25

L3= 0.01

C. State-Feedback Control with A Full-State Observer

State-Feedback Control with a Full-State Observer Design is used to control the y servo contributing to roll, the x servo for pitch, and the z servo for yaw. Before implementation on the cannon, simulation is required to ensure the control system design is good and correct. Based on Fig. 5, the closed loop system has a gain value K as follows:

K1 = 0.0004

K2 = -0.0305

K3 = 5.98

The value is obtained by **det(sI-(A-BK)) = 0.** Fig. 10 shows the response of the cannon angular position with a reference of 90 degrees.

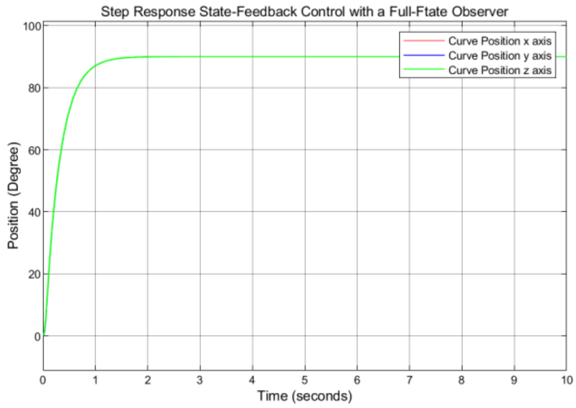

Figure 10. Cannon Simulation Response

The response of the cannon angular position shows that the cannon can reach the desired position of 90 degrees within 1.5 seconds. The response of the simulation results shows good performance when implemented. Fig. 11 shows the response of the control signal given by the controller to the cannon system.

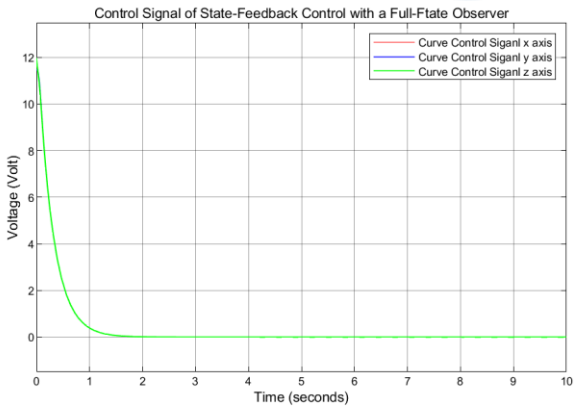

Figure 11. Control Signal Response

The control signal response shows that the voltage provided by the controller to the DC motor is a maximum of 11.7 volts. This voltage does not exceed the input voltage value given by the motor driver to the DC motor, which is 12 volts.

Then, the system was tested to get the same response curve as in the simulation. The method to see the data from the gyroscope on the cannon is to start moving the actuator until the system has a steady state.

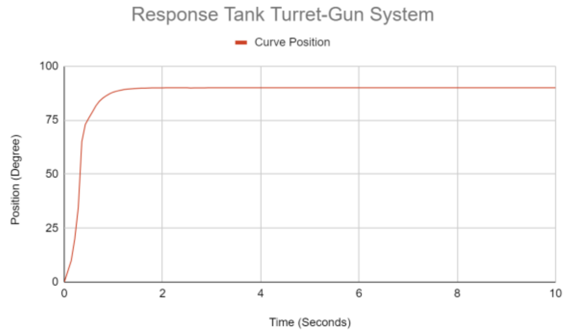

Figure 12. Cannon Implementation Response

The angular position response of the cannon's x-axis, y-axis and z-axis shows that it can reach the desired position of 90 degrees in 0.51 seconds which is the rise time and settling time and 0% overshoot, which is better than the simulation results. In this section, state-feedback control with a full-state observer test has been implemented.

V. Conclusions

It has been successfully developed to use state-feedback control with a full-state observer for cannon systems, and a pole placement was used to calculate the feedback gain K. The pole placement control approach has also been used to determine the gain of the full-state observer L. The cannon system has a settling time and rise time of 0.51 seconds, and the system is still stable. The system reaction has 0% overshoot, according to the implementation results.

Acknowledgment

The authors would like to thanks Universitas Multimedia Nusantara for supporting this research.

References

[1] Putra, D. F. A., & Muharom, A. S. (2021). The stability of cannon position on tank prototype using PID controller. Indonesian Journal of Electrical Engineering and Computer Science, 23(3), 1565-1575.

[2] Tvarozek, J., & Gullerova, M. (2012). Increasing firing accuracy of 2A46 tank cannon built-in T-72 MBT. American International Journal of Contemporary Research, 2(9), 140-156.

[3] Ma, Y., Yang, G., Sun, Q., Wang, X., & Sun, Q. (2021). Adaptive robust control for tank stability: a constraint-following approach. Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering, 235(1), 3-14.

[4] Dursun, T., Büyükcivelek, F., & Utlu, Ç. (2017). A review on the gun barrel vibrations and control for a main battle tank. Defence technology, 13(5), 353-359.

[5] Siradjuddin, I., Amalia, Z., Rohadi, E., Setiawan, B., Setiawan, A., Putri, R. I., & Yudaningtyas, E. (2018). State-feedback control with a full-state estimator for a cart-inverted pendulum

system. International Journal of Engineering & Technology, 7(4.44), 203-209.

[6] Lunze, J., & Lehmann, D. (2010). A state-feedback approach to event-based control. Automatica, 46(1), 211-215.

[7] Esmailzadeh, E., & Taghirad, H. D. (1998). Active vehicle suspensions with optimal state-feedback control. International Journal of Modelling and Simulation, 18(3), 228-238.

[8] Somwanshi, D., Bundele, M., Kumar, G., & Parashar, G. (2019). Comparison of fuzzy-PID and PID controller for speed control of DC motor using LabVIEW. Procedia Computer Science, 152, 252-260.

[9] Pinto, V. H., Gonçalves, J., & Costa, P. (2021). Model of a DC motor with worm gearbox. In CONTROLO 2020: Proceedings of the 14th APCA International Conference on Automatic Control and Soft Computing, July 1-3, 2020, Bragança, Portugal (pp. 638-647). Springer International Publishing.

[10] Aoki, M. (2013). State space modeling of time series. Springer Science & Business Media.

[11] Zadeh, L., & Desoer, C. (2008). Linear system theory: the state space approach. Courier Dover Publications.

[12] Karcanias, N., & Vafiadis, D. (2002). Canonical forms for state space descriptions. Control Systems, Robotics and Automation, 5, 361-380.

[13] Lunze, J., & Lehmann, D. (2010). A state-feedback approach to event-based control. Automatica, 46(1), 211-215.

[14] Ram, Y. M., Singh, A., & Mottershead, J. E. (2009). State feedback control with time delay. Mechanical Systems and Signal Processing, 23(6), 1940-1945.

[15] Bemporad, A., Morari, M., Dua, V., & Pistikopoulos, E. N. (2002). The explicit linear quadratic regulator for constrained systems. Automatica, 38(1), 3-20.

[16] Ruderman, M., Krettek, J., Hoffmann, F., & Bertram, T. (2008). Optimal state space control of DC motor. IFAC Proceedings Volumes, 41(2), 5796-5801.

[17] Panomrattanarug, B., Higuchi, K., & Mora-Camino, F. (2013, September). Attitude control of a quadrotor aircraft using LQR state feedback controller with full order state observer. In The SICE Annual Conference 2013 (pp. 2041-2046). IEEE.