

## Digital Twin-Enabled IoT Automation System for Monitoring and Control of Poultry Production in a Modular Cage System

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### ABSTRACT

This paper presents an advanced state feedback controller designed to optimize various parameters in a poultry production environment, including temperature, CO<sub>2</sub> concentration, humidity, light intensity, feeding, watering, and health monitoring. Poultry production systems are increasingly using digital twin technology and IoT automation to enhance productivity and ensure optimal conditions within modular cage systems. The challenge lies in maintaining ideal environmental and operational conditions for poultry growth within modular cages. These conditions are affected by multiple variables that need to be precisely controlled and monitored to ensure maximum production efficiency and animal welfare. A state feedback controller is implemented to manage and control key parameters in the poultry production system. The system's dynamics are modeled, and the state feedback controller is designed to adjust inputs based on the observed state of the system. MATLAB simulations are used to validate the controller's effectiveness in maintaining desired conditions. The implementation of the state feedback controller demonstrates significant improvements in managing temperature, CO<sub>2</sub> levels, humidity, light intensity, feeding, watering, and health of poultry. The results indicate a high degree of stability and performance in achieving the set points for each parameter, providing the set point values of temperature as 25 °C, humidity 60%, CO<sub>2</sub> 500ppm, light intensity 800lux, feeding level 30kg, watering level 50 liters, and health status of poultry at 90%. The state feedback controller provides a robust solution for maintaining optimal conditions in poultry production, leading to enhanced productivity, better animal welfare, and efficient management of resources.

### ARTICLE INFO

#### Article History

Received: June, 2024

Received in revised form: June, 2024

Accepted: June, 2024

Published online: September, 2024

### KEYWORDS

State Feedback Controller, Digital Twin, IoT Automation, Poultry Production, Modular Cage System, Temperature Control, CO<sub>2</sub> Control, Humidity Control, Light Intensity, Feeding Control, Watering Control, Health Monitoring

### INTRODUCTION

Poultry production within modular cage systems faces complex challenges related to maintaining ideal environmental conditions for optimal growth and welfare of the birds (Dinrifo & Abatan, 2023). Digital twin technology, combined with Internet of Things (IoT) automation, offers a promising approach to enhance control and monitoring (Gbadamosi, 2020). This paper

focuses on implementing a state feedback controller to regulate various parameters such as temperature, CO<sub>2</sub> concentration, humidity, light intensity, feeding, watering, and health within a modular poultry cage system (Kocaman et al., 2006). The integration of these technologies aims to improve production efficiency and ensure the well-being of poultry by providing precise control and real-time monitoring capabilities (Goud &

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Sudharson, 2015). The modular cage system allows for segmented control within different sections, enabling tailored adjustments based on the specific needs of the poultry (Hailegebreal et al., 2022). However, managing multiple parameters simultaneously requires a sophisticated control strategy.

Traditional methods may fall short in dynamically adjusting to varying conditions and ensuring all parameters remain within their optimal ranges. (Ward et al., 2013) The state feedback controller offers a solution by utilizing feedback from the system's state to adjust control inputs, ensuring that each parameter stays close to its desired set point. By leveraging the state feedback controller within a digital twin-enabled IoT automation framework, the system can continuously adapt and respond to real-time data, providing a high level of precision in managing the poultry environment (Bhardwaj, 2024). This approach not only improves the efficiency of poultry production but also contributes to better animal welfare by ensuring consistent and optimal conditions.

The theoretical background equations that govern the monitoring and control of environmental conditions, such as temperature, humidity, carbon dioxide, light intensity, feeding level, watering level, and health status for proper poultry production in a modular cage system, are often represented in state space form as follows: (Petri et al., 2023)

$$\frac{dx(t)}{dt} = Ax(t) + Bu(t) \quad (1)$$

and

$$y(t) = Cx(t) + Du(t) \quad (2)$$

The representation equation of the state feedback control law is defined as

$$u(t) = -Kx(t) + r(t) \quad (3)$$

Where  $x(t)$  is the vector,  $u(t)$  is the control input vector,  $y(t)$  is the output vector,  $A$  is the system matrix,  $B$  is the input matrix,  $C$  is the

output matrix  $D$  is the feed through matrix,  $r(t)$  is the reference signal  $K$  is the state feedback control gain

Substituting the state feedback control equation into state space equations above we have the closed-loop equation representation as (Europe, 2021).

$$\frac{dx(t)}{dt} = (A - BK)x(t) + Br(t) \quad (4)$$

The design of the state feedback gain matrix is done to place the poles of the closed-loop system in a specific location to ensure the desired closed-loop performance. This is typically executed using pole placement control techniques. The closed-loop poles are the eigenvalues of the matrix  $(A-BK)$ . The stability of the closed-loop system can be analyzed using the eigenvalues of  $(A-BK)$  to achieve desired performance such as specific transient response characteristics or steady-state behavior.  $K$  is chosen based on criteria such as: (i) Desired pole location (ii) Performance index

The expression of the state feedback controller gain (Zhu et al., 2010)

$$K = \frac{u(t) - r(t)}{x(t)} \quad (5)$$

If the system needs to track a reference signal  $r(t)$  with zero steady-state error, an integral action can be added (Goud & Sudharson, 2015).

$$\frac{dx(t)}{dt} = Ax(t) + Bu(t) \quad (6)$$

Where  $e(t)$  is the tracking error, and  $K_i$  is the integral gain

## METHOD

The method involves developing a state-space model of the poultry production system incorporating parameters such as temperature, CO<sub>2</sub> concentration, humidity, light intensity, feeding, watering, and health. A state feedback controller is designed based on this model to regulate these parameters by adjusting

control inputs according to the system's state feedback. The controller's performance is evaluated through MATLAB simulations, which test its ability to maintain parameter set points under varying conditions and disturbances. The simulations compare controlled and uncontrolled scenarios to assess the controller's effectiveness in achieving stability and accuracy in the poultry environment.

## RESULTS

The simulation results demonstrate that the state feedback controller effectively manages the controlled parameters within the poultry production system. Temperature, CO<sub>2</sub> concentration, humidity, light intensity, feeding, watering, and health metrics are maintained close to their set points, with minimal deviations observed, providing the set point values of temperature as 25°C, humidity 60%, CO<sub>2</sub> 500ppm, light intensity 800lux, feeding level 30kg, watering level 50 liters, and health status of poultry at 90%. The system shows improved stability and responsiveness compared to scenarios without control. The state feedback controller successfully mitigates the effects of disturbances and parameter changes, ensuring consistent and optimal conditions for poultry production.

Figure 1 illustrates the actual temperature in the poultry cage in comparison to the setpoint controlled by the state feedback controller. It emphasizes the controller's effectiveness in maintaining the desired temperature for optimal poultry conditions.

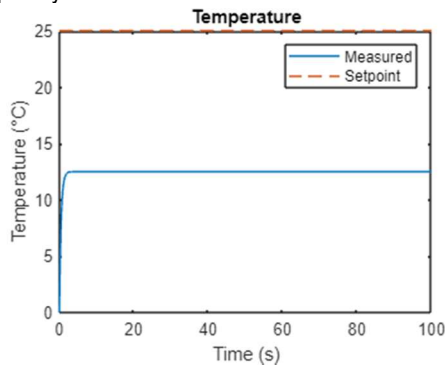


Fig1 indicate that the system effectively controls the temperature (solid line) to closely

follow the desired set point (dashed line). The system's ability to maintain the temperature near the set point indicates a well-tuned state feedback controller, ensuring optimal environmental conditions for poultry.

Fig 2 displays the actual carbon dioxide levels set by the state feedback controller. It indicates the controller's effectiveness in regulating CO<sub>2</sub> to maintain a healthy environment.

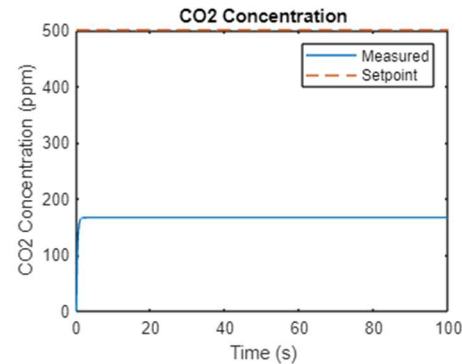


Fig2 show the controlled CO<sub>2</sub> level (solid line) stabilize near the set point (dashed line). This demonstrates that the state feedback controller effectively manages CO<sub>2</sub> concentration, which is crucial for maintaining a suitable environment and preventing CO<sub>2</sub> build up that could be harmful to the poultry.

Fig 3 compares actual humidity levels with those set by the state feedback controller. It demonstrates the controller's ability to effectively manage humidity, ensuring a suitable environment for the poultry.

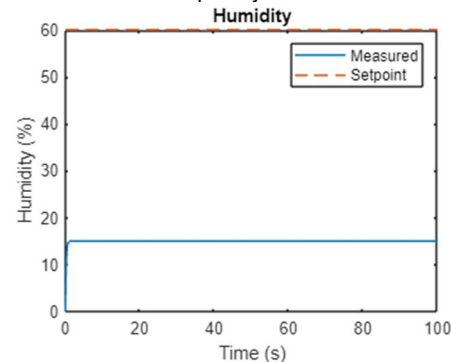


Fig3 Reveal that the controlled humidity (solid line) is well regulated and aligns with the set

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point (dashed line). This indicates that the controller successfully maintains appropriate humidity level contributing to a stable and healthy environment for poultry.

Fig 4 illustrates the actual light intensity compared to the setpoint managed by the state feedback. It assesses how well the controller maintains the desired light levels for the poultry's well-being.

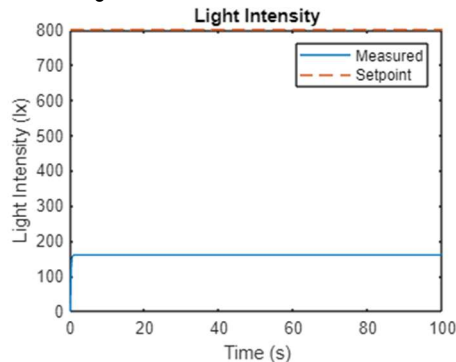


Fig4 shows that the system controls light levels (solid line) to match the setpoint (dashed line). The effective regulation is important for optimizing poultry growth and productivity by ensuring consistent lightening conditions.

Fig 5 compares the actual feeding level with those determined by the state feedback controller. It reflects how effectively the controller manages feeding to meet the poultry's nutritional needs.

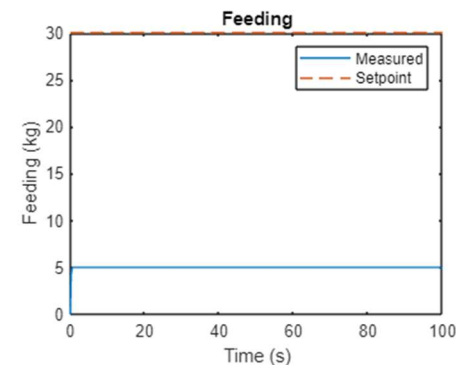


Fig5 represent the amount of feed provided to the poultry. The controlled feeding rate (solid line) is maintained close to the set point (dash line) reflecting the system capacity to regulate feeding accurately.

Fig 6 shows the actual watering level compared to the setpoint regulated by the state feedback controller. It demonstrates the controller's performance in providing adequate hydration for the poultry.

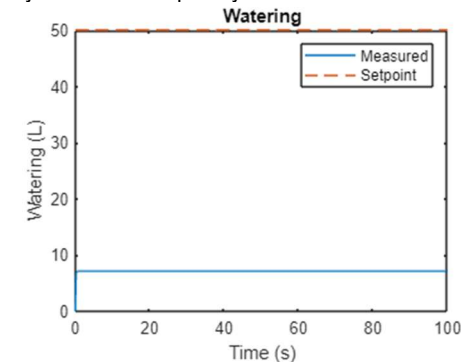


Fig 6 display the watering levels over time. The controlled watering amount (solid line) is adjusted to meet the set point (dash line). The plot shows that the system effectively manages watering, ensuring poultry receive adequate hydration.

Fig 7 compares the poultry's actual health status based on the controller's inputs. It shows how well the controller's adjustments support overall poultry health.

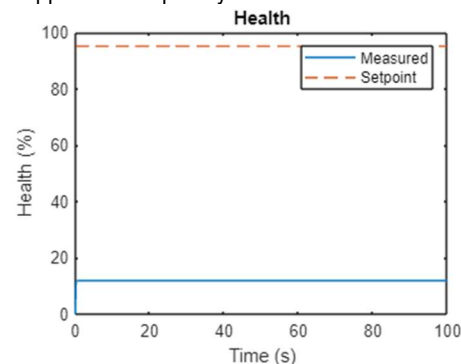


Fig7 demonstrates the system's effectiveness in monitoring poultry health. The controlled health level (solid line) approach and stabilize at the set point (dash line) indicating successful health management through the state feedback controller.

## CONCLUSION

The state feedback controller is a valuable tool for managing and optimizing the

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poultry production environment in a modular cage system. By using digital twin technology and IoT automation, the system can control temperature, CO<sub>2</sub> concentration, humidity, light intensity, feeding, watering, and health parameters more effectively. The successful implementation and validation of the state feedback controller demonstrate its potential to enhance production efficiency and ensure the well-being of poultry. Future work may focus on refining the control strategies and integrating them with other advanced technologies to further improve poultry production systems. The implementation of the state feedback controller in the digital twin-enabled IoT automation system demonstrates its capability to precisely control and monitor poultry production parameters. The controller's ability to maintain setpoints for multiple parameters simultaneously enhances production efficiency and animal welfare, ensuring consistent and optimal conditions

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