CHAPTER V
CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

Based on the implementation and testing results of the Internet of Things (IoT)-based Smart Egg Incubator using the Interval Type-2 Fuzzy Logic Controller (IT2-FLC), the following conclusions can be drawn:

1. The temperature and humidity control system for the Smart Egg Incubator was successfully designed and implemented using an ESP32 microcontroller, DS18B20 temperature sensors, DHT22 humidity sensors, a water level sensor, and actuators consisting of incandescent lamps, fans, a humidifier, a water pump, and an egg turning motor. The system was also successfully integrated with Internet of Things (IoT) technology through the Blynk IoT platform and the Telegram Bot, enabling real-time monitoring and remote control. The functional testing results demonstrated that all hardware and software components operated according to the proposed system design.
2. The Interval Type-2 Fuzzy Logic Controller (IT2-FLC) was successfully implemented to automatically regulate temperature and humidity based on the control error. The experimental results showed that the system was capable of achieving and maintaining the incubation conditions at the temperature setpoint of 37.5°C and the humidity setpoint of 60%RH with relatively small fluctuations. The 21-day stability test showed an average temperature of 37.53°C with an MAE of 0.12°C, an RMSE of 0.15°C, and a standard deviation of 0.15°C. Similarly, the average humidity was 59.78%RH, with an MAE of 0.90%RH, an RMSE of 1.12%RH, and a standard deviation of 1.11%RH. These results indicate that the proposed system was able to maintain stable incubation conditions throughout the incubation period.
3. Based on the control system evaluation, the IT2-FLC demonstrated effective control performance. For temperature regulation, the controller achieved an MAE of 0.10°C, an RMSE of 0.12°C, a rise time of 18.30 minutes, a settling time of 21.30 minutes, and an overshoot of 0.53%, indicating that the system reached the desired setpoint with high accuracy and maintained stable

temperature regulation. For humidity regulation, the controller achieved an MAE of 0.13%RH, an RMSE of 0.15%RH, a rise time of 3.30 minutes, a settling time of 4.30 minutes, and an undershoot of 0.42%, demonstrating a fast and stable humidity response around the desired setpoint. Furthermore, the egg hatching experiment achieved a 100% hatching success rate for all fertile eggs, confirming that the developed system was capable of providing suitable environmental conditions for successful chicken egg incubation.

5.2. Recommendations

Based on the findings of this study, the following recommendations are proposed for future research:

1. Future hatching experiments should involve a larger number of eggs and be conducted over multiple incubation cycles to obtain more representative data, enabling a more reliable statistical analysis of the hatching success rate.
2. Humidity sensors with higher accuracy and faster response times, such as the SHT31 or SHT40, may be employed to improve the quality of the feedback data provided to the controller, thereby enhancing humidity control performance.
3. The membership function parameters of the IT2-FLC can be optimized using optimization techniques such as Particle Swarm Optimization (PSO), Genetic Algorithm (GA), or Grey Wolf Optimizer (GWO) to automate the tuning process and further improve control performance.
4. Future studies may employ heating elements with higher power capacity and better thermal characteristics to accelerate the temperature rise inside the incubator. The use of a more efficient heater is expected to reduce the rise time and improve the overall temperature control performance.
5. The system can be enhanced by integrating a camera module, such as the ESP32-CAM, to provide real-time visual monitoring of the incubation process. This feature would allow users to remotely observe the condition of the eggs and the hatching process, thereby improving the overall monitoring capability of the system.
6. The system can also be improved by incorporating a backup power supply, such as an Uninterruptible Power Supply (UPS) or a rechargeable battery, to ensure

continuous operation during power outages. This enhancement is expected to maintain stable temperature and humidity conditions throughout the incubation period while reducing the risk of hatching failure caused by interruptions in the electrical power supply.