

CHAPTER 5

CONCLUSIONS AND SUGGESTIONS

5.1 Conclusion

Based on the design, implementation, and testing of the Internet of Things (IoT) -based eco-enzyme reactor monitoring and control system using the Interval Type-2 Fuzzy Logic (IT2FL) algorithm that has been carried out, several conclusions can be drawn as follows:

1. Successful System Design and Development

The goal of designing and building an Internet of Things (IoT) system based on Fuzzy Logic has been successfully achieved. The system was successfully designed using a hardware architecture with the ESP32 NodeMCU as a control center integrated with a pH sensor, temperature sensor (DS18B20), and gas sensor (MQ-135). The accuracy of the temperature sensor has an error of 0.42% and the pH sensor has an accuracy of above 94% (MAE 0.187 - 0.238) proving that the sensor can read the data well and has high accuracy. In addition, an algorithm based on Interval Type-2 Fuzzy Logic (IT2FL) was successfully implemented on a microcontroller to process data locally, and the system was able to facilitate real-time monitoring and control of the eco-enzyme fermentation process through the Blynk cloud platform.

2. Successful Implementation for Parameter Stability

The goal of implementing an IoT system based on Type-2 Fuzzy Logic to maintain the stability of the main fermentation parameters (pH, temperature, and gas) has been successfully realized. The implementation of fuzzy calculations with Karnik-Mendel type reduction on microcontrollers proved to be successful and precise in executing automatic actuators. The system responsively activates the Peltier cooler and water pump when the temperature is detected hot, opens the solenoid valve to drain the gas when excess accumulation occurs, and turns on the buzzer as an early warning indicator when the acidity degree (pH) enters the fail/alkaline state, so that the safety and ideal environment of fermentation are maintained independently without manual intervention.

3. Successful System Performance Evaluation on the MSME Scale

The purpose of evaluating system performance in improving consistency, quality, and safety at the MSME scale has been answered through comprehensive testing. Evaluation shows that the sensor instrument operates with an excellent level of accuracy, where the accuracy of the temperature sensor and pH sensor is below 1% proving that the sensor has a small error value and high accuracy. In addition, IoT communication systems are proven to be reliable with an average data transmission latency of 1.0 seconds without packet loss. The direct implementation of the Mamah Endut MSME organic reactor proves that this system is effectively able to overcome the uncertainty of parameter fluctuations, prevent the risk of explosion due to anaerobic gas pressure, and support an objective monitoring process to achieve consistency in the quality of eco-enzyme raw materials.

5.2 Suggestions

Although the system has been operating well as designed, there are several aspects that can be developed to improve future research, including:

1. Testing on the Full Fermentation Cycle

Given that the system testing and data collection in this study are limited to one active fermentation cycle (for 30 days), it is recommended that further research conduct continuous monitoring of the tool until it reaches a perfect eco-enzyme ripening cycle (over a span of 3 months or 90 days). This aims to monitor carbon dioxide gas fluctuations and acidity stability (pH) more comprehensively from the initial phase to the harvest phase.

2. Use of Industry Standard Sensors

To obtain a higher level of precision especially at the extreme pH range (strong acids), further research can consider the use of industrial-grade pH probes that have better linear sensitivity at conditions below pH 4.0.

3. Self-Built Dashboard and Database Development

To overcome Blynk's limitations in long-term data storage, future developments should build standalone web applications (e.g., using Laravel) integrated with relational databases (e.g., PostgreSQL) to continuously record and analyze historical fermentation logs.