CHAPTER I
INTRODUCTION

1.1 Background

Oyster mushroom (*Pleurotus ostreatus*) is one of the horticultural commodities with significant economic value and continuously increasing market demand in Indonesia. The success of oyster mushroom cultivation is highly dependent on the stability of microclimate parameters, particularly temperature and relative humidity inside the cultivation house. According to Chang and Miles[1], oyster mushrooms require an optimal temperature range of 24°C–28°C and relative humidity between 80%–90% during fruiting body development. Deviations from these environmental conditions may negatively affect mycelial growth, primordia formation, and harvest quality[2]. Therefore, maintaining stable environmental conditions is an essential aspect of modern mushroom cultivation management.

Indonesia's tropical climate is characterized by dynamic fluctuations in temperature and humidity. Daily temperature variations in tropical lowland areas may range from 5°C to 10°C, while humidity levels are strongly influenced by solar radiation, rainfall, and airflow[3]. These environmental changes often affect the internal conditions of mushroom cultivation houses, especially small-scale structures with limited thermal insulation. Royse et al.[4] reported that uncontrolled temperature and humidity fluctuations are among the primary causes of crop failure in tropical oyster mushroom cultivation. Consequently, an adaptive and real-time environmental control system is required to maintain stable microclimate conditions.

Another challenge in microclimate control is the presence of uncertainty originating from sensor inaccuracies, signal noise, actuator variability, and internal environmental dynamics[5]. The humidification process, uneven air circulation, and heat generated by actuators may introduce instability in sensor readings. In practical conditions, sensors such as the SHT31 possess measurement tolerances that may lead to deviations from actual environmental conditions. Such uncertainty may reduce control accuracy if not properly addressed within the control algorithm.

The advancement of Internet of Things (IoT) technology has enabled the development of automated and real-time monitoring systems in modern agriculture. IoT architectures integrate sensors, actuators, controllers, and communication platforms into interconnected systems capable of remote monitoring and autonomous operation[6]. In precision agriculture, IoT-based systems have been widely implemented for greenhouse climate control, irrigation automation, and environmental monitoring[7]. In oyster mushroom cultivation, IoT technology enables continuous environmental data acquisition, remote monitoring, and automated actuator control [8]. In this study, environmental monitoring is performed through the Blynk platform, while historical data logging is stored in Google Spreadsheet for further evaluation and analysis.

To maintain stable microclimate conditions, this research adopts a hybrid cooling-heating mechanism. The cooling system utilizes a thermoelectric Peltier module due to its compact size, ease of integration with microcontrollers, and suitability for micro-scale prototypes. Meanwhile, heating is performed using a resistive heater, and humidity control is supported by an ultrasonic mist maker[9],[10]. The integration of multiple actuators requires an intelligent control strategy capable of coordinating system responses efficiently while minimizing operational conflicts and energy consumption.

Fuzzy Logic Control (FLC) has been widely applied in agricultural environmental control systems because of its capability to handle uncertainty and nonlinear system characteristics. Unlike conventional controllers, fuzzy logic can represent expert knowledge through linguistic rules without requiring precise mathematical models [11]. Previous studies have shown that fuzzy-based environmental control systems provide stable and smooth responses under varying environmental conditions[12]. In oyster mushroom cultivation, fuzzy logic is suitable for handling uncertain sensor measurements and actuator variability while maintaining environmental stability.

Interval Type-2 Fuzzy Logic (IT2FL) is an extension of Type-1 Fuzzy Logic introduced by Zadeh[11] and further developed by Mendel[13]. The fundamental difference lies in its ability to represent uncertainty through Upper Membership Functions (UMF), Lower Membership Functions (LMF), and the Footprint of

Uncertainty (FOU)[5]. This structure enables IT2FL to explicitly model uncertainties caused by sensor noise, linguistic ambiguity, and environmental variability [14]. Therefore, IT2FL is considered suitable for environmental control applications operating under uncertain tropical conditions such as oyster mushroom cultivation houses.

Several previous studies have demonstrated the effectiveness of IT2FL in uncertain environments. Castillo and Melin[15] reported that IT2FL controllers were capable of maintaining system stability under significant parameter uncertainty. Wu and Tan[16] applied IT2FL in greenhouse climate control and achieved stable environmental regulation under external disturbances. Similarly, Hagras[17] and Ekici and Aksoy[18] demonstrated the robustness of IT2FL in autonomous systems and HVAC applications. These findings indicate that IT2FL has strong potential for microclimate control applications in oyster mushroom cultivation.

System performance evaluation is an important aspect of control system implementation. In this study, Mean Absolute Error (MAE) and Integral Absolute Error (IAE) are used to evaluate control performance. MAE measures the average deviation between actual conditions and setpoints, while IAE evaluates the cumulative control error over time[19],[20]. The combination of these parameters provides comprehensive insight into both steady-state accuracy and dynamic system response.

This research is conducted on a micro-scale cultivation house prototype specifically designed for system testing and evaluation. The prototype approach enables controlled experimentation, lower implementation costs, and efficient performance validation before large-scale deployment[9]. The developed system integrates ESP32, SHT31 sensors, hybrid cooling-heating actuators, and an IT2FL algorithm within an IoT-based automatic control framework. The control algorithm operates locally on the ESP32, ensuring continuous operation even during internet connectivity interruptions. Additionally, the system incorporates a safe mode mechanism to prevent abnormal control actions caused by invalid sensor readings.

Although numerous studies have investigated environmental control systems for mushroom cultivation, most employ conventional on-off or PID control methods that have limited capability in handling environmental uncertainty formally [21]. Three major research gaps are identified in this study. First, the implementation of IT2FL for tropical micro-scale mushroom cultivation systems remains limited. Second, the use of MAE and IAE for evaluating mushroom cultivation control performance has not been extensively explored. Third, the integration of IT2FL with IoT-based hybrid cooling-heating systems in tropical environments remains underexplored[22]. Therefore, this research aims to contribute by implementing and evaluating an IoT-based IT2FL environmental control system for oyster mushroom cultivation houses under tropical conditions.

Based on the aforementioned background, this study focuses on designing, implementing, and evaluating an IoT-based IT2FL control system for temperature and humidity regulation in a micro-scale oyster mushroom cultivation house. The novelty of this research lies in the implementation of IT2FL within a hybrid cooling-heating system integrated with IoT technology under tropical environmental conditions, with performance evaluation based on MAE and IAE parameters.

1.2 Problem Formulation

Based on the background described above, the research problems are formulated as follows:

1. How can IT2FL be implemented in an IoT-based temperature and humidity control system for oyster mushroom cultivation houses?
2. How does the IT2FL control system respond to fluctuations in temperature and humidity sensor readings within a tropical micro-scale environment?
3. How effective is the IT2FL control system in maintaining temperature and humidity close to the predefined setpoints based on MAE and IAE evaluation parameters?

1.3 Research Objectives

The objectives of this study are as follows:

1. To design and implement an IoT-based automatic temperature and humidity control system using the Interval Type-2 Fuzzy Logic method for oyster mushroom cultivation houses.
2. To analyze the performance of the IT2FL system in maintaining stable temperature and humidity according to predefined setpoints during the testing period.
3. To evaluate the control system performance using Mean Absolute Error (MAE) and Integral Absolute Error (IAE) parameters.

1.4 Research Benefits

A. For the Author

This research serves as a medium for developing both academic and practical competencies in Internet of Things (IoT), Type-2 Fuzzy Logic, and microcontroller-based automation systems. The study also provides practical experience in intelligent control system design and quantitative data analysis.

B. For Future Researchers

The results of this study may serve as a reference for further research involving more complex IT2FL implementations, machine learning integration, or similar applications in other agricultural sectors. This research also contributes to the documentation of IT2FL implementation in fluctuating tropical environments.

C. For Oyster Mushroom Farmers

The developed system is expected to provide a practical solution for automatic temperature and humidity control in oyster mushroom cultivation houses. The system may help reduce manual intervention, maintain stable microclimate conditions, and improve environmental monitoring efficiency.

1.5 Scope and Limitations

To maintain the focus and feasibility of the study, several limitations are defined as follows:

1. This study focuses on the design and implementation of an IoT-based temperature and humidity control system using the Interval Type-2 Fuzzy Logic (IT2FL) method.
2. Controlled environmental parameters are limited to air temperature within the range of 24–28°C and relative humidity within 80–90% RH.
3. The hardware components used include SHT31 temperature-humidity sensors, intake fans, exhaust fans, circulation fans, heaters, Peltier coolers, mist makers, relay modules, and ESP32 DevKit V1 as the primary controller and IoT communication unit.
4. The research is conducted on a closed micro-scale oyster mushroom cultivation prototype and does not directly represent industrial-scale cultivation systems.
5. Data collection is performed for 10 days with a 1-minute interval, and biological harvest productivity is not evaluated.
6. This study does not compare IT2FL performance with other control methods.