CHAPTER I
INTRODUCTION

This chapter presents the fundamental basis of the research, including the problems to be addressed and the objectives to be achieved. It describes the research background, problem formulation, research objectives, significance of the study, and research limitations, which define the direction and scope of the subsequent research.

1.1. Background

The poultry farming industry is one of the strategic sectors that supports national food security and provides animal-based protein for the community. Poultry products, particularly meat and eggs, serve as primary sources of protein for a large proportion of Indonesia's population. Consequently, the sustainability of this industry largely depends on its ability to meet the continuously growing demand driven by population growth and increasing public awareness of the importance of consuming nutritious food [1], [2]. To improve production quality, the egg incubation stage plays a crucial role, as the quality of poultry chicks is highly influenced by the environmental conditions maintained throughout the incubation period [3]. Several environmental variables play essential roles in the success of egg incubation, particularly temperature, humidity, ventilation or oxygen exchange, and egg turning, each of which has a significant physiological influence on embryonic development. The optimal incubation temperature ranges from 37°C to 38°C, while the ideal relative humidity is between 55% and 65%. Deviations from these optimal ranges can significantly reduce the hatchability rate [4]. Adequate oxygen supply through proper ventilation is also critical for embryonic metabolism, while regular egg turning prevents the embryo from adhering to the eggshell membrane and promotes symmetrical embryonic development [5].

In Indonesia, many poultry farmers still rely on traditional incubation methods, which have several limitations in maintaining optimal incubation conditions. Temperature and humidity are generally regulated manually, making it difficult to maintain stable environmental conditions inside the incubator [6]. The stability of these two parameters is crucial for embryonic development, as even minor fluctuations in temperature or humidity can disrupt physiological processes and increase the risk of embryonic mortality before hatching [7]. Furthermore, monitoring systems that depend primarily on direct observation often result in delayed adjustments when environmental conditions change. Consequently, these limitations lead to lower hatchability rates and may cause economic losses due to the increased number of eggs that fail to hatch [8].

Recent technological advancements have introduced various approaches to improve the efficiency of the incubation process, one of which is the implementation of the Internet of Things (IoT) and fuzzy logic-based control systems. IoT technology enables real-time monitoring of incubator conditions through sensors and internet connectivity, allowing users to remotely monitor and control temperature and humidity using mobile devices [9]. Meanwhile, fuzzy logic is employed to automatically regulate temperature and humidity based on measured environmental conditions [10]. This control approach is capable of mimicking human decision-making by taking into account uncertainty and variations in environmental conditions. To further enhance its performance, the Interval Type-2 Fuzzy Logic Controller (IT2-FLC) was introduced to improve the system's robustness against disturbances, such as sensor noise and variations in environmental parameters [11]. The integration of the Interval Type-2 Fuzzy Logic Controller (IT2-FLC) with the Internet of Things (IoT) is expected to create a smarter, Numerous previous studies have investigated the application of fuzzy logic controllers and Internet of Things (IoT) technology in control systems using various approaches. Al-Mashhadany *et al.* [13] demonstrated that the Modified Interval Type-2 Fuzzy Logic Controller (MIT2FLC) outperformed both the Proportional–Integral–Derivative (PID) controller and the Type-1 Fuzzy Logic Controller (T1FLC) in handling uncertainty, sensor noise, and nonlinear system dynamics in Brushless DC (BLDC) motor control. This superior performance was achieved through the Footprint of Uncertainty (FOU) mechanism, which improved the controller's robustness against disturbances. Wahyuni *et al.* [4] developed an IoT-based smart egg incubator employing the Mamdani Fuzzy Logic algorithm to automatically regulate temperature and humidity. However, the reported hatchability rate reached only 15%, which was attributed to the use of relatively simple fuzzy rules and insufficient documentation of the membership functions. Another study by Prabowo *et al*. [14] developed an IoT-based egg incubator using a Proportional–Integral–Derivative (PID) controller, an ESP32 microcontroller, and a DHT21 sensor to maintain temperature stability. However, the system still required manual controller tuning and exhibited limited responsiveness to changes in environmental conditions. Based on these findings, the implementation of an Interval Type-2 Fuzzy Logic Controller (IT2-FLC) is considered a promising approach for IoT-based egg incubation systems due to its superior capability to handle sensor measurement uncertainty, temperature and humidity variations, and external disturbances. Consequently, IT2-FLC is expected to improve control accuracy, system stability, and hatchability compared with conventional control methods and the Type-1 Fuzzy Logic Controller (T1FLC).

Based on the aforementioned background, this study aims to design and implement an Interval Type-2 Fuzzy Logic Controller (IT2-FLC) as the primary control system for automatically and accurately maintaining stable temperature and humidity inside an egg incubator. The integration of the Interval Type-2 Fuzzy Logic Controller (IT2-FLC) with Internet of Things (IoT) technology enables real-time monitoring of incubation conditions through digital devices, allowing the incubation process to operate more efficiently and stably while achieving a higher hatchability rate than traditional methods. Furthermore, this research is expected to contribute to the advancement of modern poultry farming technology by providing an adaptive and efficient solution that supports productivity in the digital era.

1.2. Research Question

Based on the background presented above, this study addresses the following research problems:

1. How can a temperature and humidity control system for an egg incubator be designed and implemented with the integration of Internet of Things (IoT) technology?
2. How can the implementation of an Interval Type-2 Fuzzy Logic Controller (IT2-FLC) improve the stability and accuracy of temperature and humidity control in an egg incubator?

3. How does an Interval Type-2 Fuzzy Logic Controller (IT2-FLC)-based control system perform in maintaining the stability of temperature and humidity?

1.3. Research Objectives

Based on the research problems presented in the previous section, the objectives of this study are as follows:

1. To design and implement an Internet of Things (IoT)-based egg incubator capable of monitoring temperature and humidity in real time.
2. To develop and implement an Interval Type-2 Fuzzy Logic Controller (IT2-FLC) to optimize temperature and humidity control in the egg incubator.
3. To evaluate the performance of the Interval Type-2 Fuzzy Logic Controller (IT2-FLC)-based control system in maintaining the stability of temperature and humidity.

1.4. Research Benefits

Based on the research background and objectives, this study is expected to provide the following contributions:

1. For the Author: To enhance the author's knowledge and competence in intelligent control systems, particularly the application of the Interval Type-2 Fuzzy Logic Controller (IT2-FLC) in embedded systems and the Internet of Things (IoT), while fulfilling the academic requirements for obtaining a bachelor's degree.
2. For Users: To provide an efficient and precise technological solution for automatically controlling the temperature and humidity of an egg incubator, improving hatchability, reducing economic losses, and enabling remote monitoring of the incubation process.
3. For Researchers and Readers: To contribute to the advancement of knowledge in the fields of artificial intelligence and adaptive control systems, while serving as a reference for future studies on fuzzy control systems, the Internet of Things (IoT), and precision agriculture technologies.

1.5. Scope of the Study

To ensure that the research remains focused on its primary objectives, the scope of this study is defined by the following limitations:

1. Remote monitoring and control are implemented using Internet of Things (IoT) technology based on an ESP32 microcontroller, the Blynk IoT platform, and a Telegram Bot.
2. This study does not include an analysis of the power consumption or energy efficiency of the developed system.
3. Environmental control within the incubator is limited to temperature and humidity, without considering other parameters such as CO_2 concentration and air quality.
4. System performance is evaluated using a temperature setpoint of 37.5°C and a humidity setpoint of 60%RH, which are appropriate for chicken egg incubation.
5. The experimental evaluation is limited to native chicken eggs (*Gallus gallus domesticus*) and does not include eggs from other poultry species.