# CHAPTER I
# INTRODUCTION

## 1.1. Background

A vivarium is an artificial ecosystem enclosed within a controlled environment that is designed to accurately replicate natural habitats for animals and other living organisms [1]. Maintaining the balance of environmental parameters, such as temperature, air humidity, and soil moisture, is essential to ensure the healthy growth of plants and supporting organisms. Therefore, regulating these environmental conditions is a fundamental requirement for establishing a healthy and sustainable ecosystem while minimizing human intervention [2].

Over time, the concept of a bioactive ecosystem has become increasingly popular because it integrates natural interactions between plants and decomposer microorganisms to create a self-sustaining nutrient cycle [3]. A bioactive system relies on detritivorous organisms, including bacteria and other decomposers, which convert biological waste into natural nutrients that support the ecosystem. Consequently, the success of a bioactive vivarium depends greatly on environmental conditions that can sustain the survival and activity of these microorganisms, allowing the decomposition process to continue continuously. [4].

The Crocodile Skink (*Tribolonotus gracilis*) is a terrestrial lizard species native to the tropical rainforests of New Guinea [5]. In its natural habitat, it inhabits humid forest floors and is commonly found beneath dense vegetation or coconut fiber near water sources [6]. Compared with other members of the *Scincidae* family, this species exhibits several distinctive biological characteristics, including the ability to produce vocalizations as a defense mechanism It also possesses unique ventral glands and volar pores. However, Crocodile Skinks are highly sensitive to sudden temperature fluctuations, which can weaken their immune system. Thermal stress increases their susceptibility to opportunistic bacterial infections, particularly *Aeromonas hydrophila*, a pathogen capable of causing systemic infection and death within three to seven days when the animal's immune system is compromised [8].

In addition to the biological risks, environmental instability also results in considerable economic losses. As a high-value commodity in the international reptile trade, records indicate that between 2000 and 2014, approximately 15,630 live *Tribolonotus* specimens were imported into the United States, including 3,527 *Tribolonotus gracilis*. Most of these specimens originated from Indonesia. Furthermore, the European Union recorded the import of 6,805 live skinks between 2000 and 2016, of which 5,955 were identified as *Tribolonotus gracilis*. With market prices reaching several hundred US dollars per pair, mortality caused by environmental control failures represents a substantial financial loss for both hobbyists and breeders[9].

To maintain ecosystem stability, several key environmental parameters must be carefully controlled, particularly temperature, air humidity, and soil moisture [10]. Any imbalance in these parameters can disrupt biological processes and compromise the stability of this sensitive tropical ecosystem. Unstable temperatures may induce metabolic stress in living organisms, while low air humidity can cause plants to wilt[2]. Likewise, insufficient soil moisture can reduce or eliminate decomposer microorganisms that are essential for recycling biological waste within the bioactive system. Therefore, maintaining these environmental parameters within their optimal ranges is necessary to preserve ecosystem health while minimizing intensive manual maintenance [2].

Previous studies have demonstrated the significant potential of the Proportional-Integral-Derivative (PID) control method optimized using the Particle Swarm Optimization (PSO) algorithm for maintaining stable environmental conditions in sensitive microclimates [11]. This approach automatically determines optimal controller parameters to reduce common control problems, such as excessive overshoot, which frequently occurs in conventional PID tuning methods. The resulting control system is capable of maintaining stable air temperature and soil moisture, thereby creating environmental conditions suitable for sustaining the bioactive ecosystem [12].

Other studies have also shown that Internet of Things (IoT) technology is effective for maintaining environmental parameters within their desired ranges through real-time remote monitoring [12]. Sensor data are processed by the control system and transmitted to the Blynk platform, allowing users to monitor environmental conditions directly through a smartphone. Based on sensor measurements, the system can automatically activate actuators such as water pumps, thereby maintaining ecosystem stability without requiring continuous human intervention [13].

Furthermore, the combination of PID control and PSO optimization provides an effective approach for identifying optimal controller parameters within complex search spaces [11]. The PSO algorithm automatically searches for the optimal proportional (Kp), integral (Ki), and derivative (Kd) gains, resulting in more accurate and adaptive control performance. The optimization process consists of four primary stages: particle population initialization, fitness evaluation, velocity and position updates, and the determination of the best controller parameters [14]. Consequently, the PID-PSO method enables the control system to respond more effectively to unpredictable environmental changes [12].

Based on the analysis of previous studies and the identified challenges, this research proposes the development of an Internet of Things (IoT)-based monitoring and environmental control system for a bioactive vivarium. The proposed system employs the Particle Swarm Optimization (PSO) algorithm to optimize the PID controller, while the ESP32 microcontroller serves as the primary processing unit. The main objective of this study is to maintain stable environmental conditions within the vivarium, thereby supporting the healthy growth of plants and decomposer microorganisms that are essential for sustaining the bioactive ecosystem.

Considering the biological characteristics of the Crocodile Skink, environmental stability is an essential factor for its survival. Unstable habitat conditions can weaken the animal's immune system, making it highly susceptible to fatal bacterial infections caused by *Aeromonas hydrophila*, which may lead to death within only three to seven days. From an economic perspective, such mortality also represents a substantial financial loss due to the species' high commercial value in the international reptile market. Therefore, this research integrates automated actuators, including a Peltier cooling module, a mist maker, and a mini submersible pump, to accurately replicate the environmental conditions of a tropical rainforest while supporting the bioactive interactions between plants and decomposer microorganisms. In addition, IoT technology provides continuous remote monitoring capabilities.

## 1.2. Research Problems

Based on the background presented above, the research problems addressed in this study are as follows:

1. How can an IoT-based environmental control system utilizing a PID controller optimized with the Particle Swarm Optimization (PSO) algorithm be designed to monitor and regulate environmental parameters in a bioactive vivarium?
2. How effectively can the proposed PID-PSO-based IoT system maintain the stability of key environmental parameters, including air temperature, air humidity, and soil moisture, in accordance with the natural habitat requirements of the Crocodile Skink?
3. How does the performance of the PID controller optimized using the PSO algorithm compare in minimizing overshoot and maintaining stable environmental conditions within a bioactive ecosystem?
4. How can an ESP32-based IoT system be designed to provide real-time and remote monitoring of environmental conditions in a bioactive vivarium?

## 1.3. Research Objectives

Based on the research problems, the objectives of this study are as follows:

1. To design and implement an automated environmental control system based on the ESP32 microcontroller using a Proportional-Integral-Derivative (PID) controller optimized with the Particle Swarm Optimization (PSO) algorithm to regulate environmental parameters within a bioactive vivarium.
2. To maintain the stability of the artificial habitat's microclimate by controlling the air temperature within the range of 22°C–25°C, the air humidity between 70%–85%, and the soil moisture at approximately 70%, thereby supporting the sustainability of the bioactive ecosystem and its self-sustaining nutrient cycle.
3. To evaluate the effectiveness of the PSO algorithm in determining the optimal PID parameters (Kp, Ki, and Kd) for minimizing overshoot and reducing system response time, thereby ensuring a stable and biologically suitable environment for the Crocodile Skink.

4. To develop an Internet of Things (IoT)-based monitoring platform that enables users to remotely monitor environmental conditions inside the bioactive vivarium in real time using smart devices.

### 1.4. Scope and Limitations

To maintain the focus and accuracy of this research, the study is subject to the following limitations:

1. This study is limited to the implementation of an automated local environmental control system and real-time monitoring of the vivarium's microclimate.
2. Internet of Things (IoT) technology is employed solely for remote monitoring of environmental parameters.
3. The ESP32 microcontroller serves as the primary processing unit responsible for managing the DHT22 temperature and humidity sensor, the soil moisture sensor, and the actuators, including the Arduino-based mist maker, mini submersible pump, and Peltier cooling module.
4. The control system focuses exclusively on three environmental parameters: air temperature, air humidity, and soil moisture.
5. The control strategy is limited to the implementation of the Particle Swarm Optimization (PSO) algorithm for determining the optimal PID controller parameters required to maintain environmental stability.
6. The system is designed to replicate the environmental conditions of a tropical rainforest, with a temperature range of 22°C–25°C, air humidity between 70%–85%, and soil moisture maintained at approximately 70%.
7. The system is designed based on a low-maintenance concept by relying on fully automated temperature and humidity regulation.
8. Experimental testing is conducted using a bioactive vivarium measuring 70 cm × 35 cm × 35 cm, containing tropical plants and decomposer microorganisms.
9. The experimental evaluation is conducted over a period of 10 consecutive days.
10. The system is powered by an AC power supply through an adapter without the use of a battery backup system.

## 1.5. Research Benefits

1. For the Researcher

   This research provides practical experience in designing automated environmental control systems, implementing the Particle Swarm Optimization (PSO) algorithm for optimizing PID controllers, and managing environmental parameters within a bioactive vivarium. Furthermore, it enhances the researcher's understanding of maintaining the stability of tropical ecosystems by controlling key environmental variables, including air temperature, air humidity, and soil moisture. Through the implementation of the PID-PSO approach, the researcher also gains valuable experience in developing a control system that is both precise and adaptive to complex microenvironmental dynamics.

2. For Future Research

   This study is expected to serve as a reference for future research related to IoT-based environmental control systems employing PID-PSO or other optimization techniques. The findings provide opportunities for further investigation into advanced environmental control strategies, not only for regulating temperature and humidity but also for developing adaptive control systems for other exotic animal habitats. Consequently, this research contributes to the advancement of intelligent habitat automation and technology-assisted wildlife conservation.

3. For Crocodile Skink Owners and Vivarium Enthusiasts

   The proposed system provides Crocodile Skink owners and vivarium enthusiasts with an effective solution for maintaining stable environmental conditions by automatically regulating temperature, air humidity, and soil moisture. By minimizing sudden environmental fluctuations, the system helps improve animal welfare while supporting the sustainability of the bioactive ecosystem. In addition, the IoT-based monitoring platform enables users to observe habitat conditions remotely, facilitating routine maintenance planning and allowing timely preventive actions without requiring continuous manual inspection.