



# “Smart Universal Automated Incubator System”

Model Name: “EggSync 360”

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This project report has been submitted in fulfilment of the requirements for the degree  
of **Bachelor of Science in Software Engineering**

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This thesis titled on "Smart Universal Automated Incubator System — EggSync 360", submitted by **Hisam Maohammad Nakib (ID: 221-35-1067)** to the Department of Software Engineering, Daffodil International University has been accepted as satisfactory for the partial fulfillment of the requirements for the degree of Bachelor of Science in Software Engineering and approval as to its style and contents.

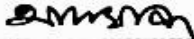
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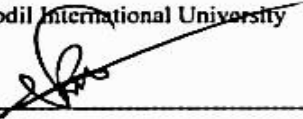
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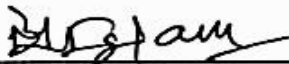
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# **Smart Universal Automated Incubator System EggSync 360**

**Hisam Mohammad Nakib**

Project submitted in fulfillment of the requirements  
for the award of the degree of  
Bachelor of Science/Master of Science

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## DEDICATION

I offer this project to my most cherished **mother**, with all my love and heart, and all the possible gratitude, as her unending prayers, her unconditional love, and her unwavering support were my greatest asset at all the stages of my life. Nothing would have been possible to me without her blessings.

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## **ABSTRACT**

This project outlines the design and development of the Smart Universal Automated Incubator System, which is called EggSync 360, which is a high-precision, industrial-grade incubation system developed to be a high-precision system. It is designed to allow the system to overcome the constraints of traditional and current incubators with a combination of high performance sensory technologies, intelligent automation, and IoT-based monitoring to reach a much higher level of hatching accuracy and operation efficiency.

EggSync 360 has several environmental monitors such as temperature, humidity, oxygen, and gas detectors that monitor the incubation conditions at all times accurately. The microcontroller of the system is an ESP32 which processes real-time data, controls the environment, supports wireless communication, and provides safety mechanisms of the system. Its most prominent features are automated circulation of air, using physics-based calculations, a dedicated heating chamber to avoid direct exposure to heat, UV sterilization, HEPA filtration system, in-built cooling and ventilation mechanisms, and automated control of gasses to preserve the optimal air quality. The incubator also accommodates other types of eggs and it will dynamically change its settings depending on the type of species chosen.

With mobile connectivity and real-time notification, users will be able to track incubation process remotely, get alerts of key events, and track key activities like schedules of candling and hatching timelines. The modularity of the system, its efficiency in terms of energy, and its compatibility with other power sources such as solar, UPS, and IPS are what make it applicable both in the industries and in a rural setting.

EggSync 360, generally, is an innovative, dependable amelioration of the contemporary incubation technology, which is more precise, shows a greater incubation rate, less people engagement, and more convenient to use than the traditional ones.

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## LIST OF SYMBOLS

Symbol	Description
@	Copyright attribution symbol
%	Percentage
±	Plus–minus sign, indicating allowable deviation
°C	Degree Celsius, unit of temperature
CO <sub>2</sub>	Carbon Dioxide concentration
O <sub>2</sub>	Oxygen concentration
→	Arrow symbol indicating process flow or sequence
<input type="checkbox"/>	Checkbox symbol used for classification selection
–	En dash, used to indicate ranges
—	Em dash, used in titles and headings
•	Bullet symbol for listing items

## LIST OF ABBREVIATIONS

<b>Abbreviation</b>	<b>Full Form</b>
AC	Alternating Current
API	Application Programming Interface
CO <sub>2</sub>	Carbon Dioxide
DC	Direct Current
ESP32	Espressif 32-bit Microcontroller
GPIO	General Purpose Input Output
HEPA	High Efficiency Particulate Air
HTTP	Hypertext Transfer Protocol
IoT	Internet of Things
IPS	Instant Power Supply
MQTT	Message Queuing Telemetry Transport
PID	Proportional Integral Derivative
RH	Relative Humidity
RTM	Requirement Traceability Matrix
SRLC	Software Release Life Cycle
SMPS	Switched Mode Power Supply
UAT	User Acceptance Testing
UI	User Interface
UPS	Uninterruptible Power Supply
UV	Ultraviolet
WiFi	Wireless Fidelity

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# CHAPTER 1

## INTRODUCTION

### 1.1 Background

The high rate of development in the poultry business across the world has greatly enhanced the need to have efficient and automated systems of egg incubation which is reliable. Conventional incubators are usually poorly regulated in terms of the environment, they are not monitored in real time and lack high-tech safety measures, leading to uneven hatching rates and lack of efficiency. New industrial incubation centers need more intelligent systems that can control the temperature, humidity and air circulation of the atmosphere and gases and have minimal human interference.

In solving these issues, the Smart Universal Automated Incubator System, which is now called **EggSync 360**, has been devised as a high-tech system of incubation that combines IoT technologies, automation, and high-accuracy sensing systems. With the help of an ESP32 microcontroller featuring Wi-Fi and Bluetooth, the system allows to intelligently control several environmental variables, send real-time notifications, and make decisions based on data throughout the incubation period.

#### 1.1.1 Context and Relevance

The technologies of precision agriculture and smart farming have become very important in the recent years. Automation can significantly lead to better productivity and efficiencies in one area and that is the incubation of poultry. The available industrial incubators tend to have an uneven heat spread, poor control over the oxygen concentration, unsafe build-up of carbon dioxide, and poor monitoring.

EggSync 360 fits the trends of smart agriculture in the world by applying sensors, anticipatory environmental modification, and cloud-driven surveillance to ensure the consistency of incubating conditions. The system is very suitable in poultry farms, hatcheries, research laboratories, and agricultural automation industries due to this relevance.

#### 1.1.2 Problem Identification

In general, the conventional and even industrial-grade incubators have several common issues:

- Unstable humidity and temperature conditions.
- Minimal or absent oxygen and poisonous gas overseeing.
- Slow circulation of air which results in hot spots and poor hatching.
- Lack of real time remote monitoring and alerts.
- Large chance of overheating or environmental imbalance.
- Poor support of multi-species egg incubation.
- Reliance on manual calibration and control.

Such gaps lower the hatching success rates, raise the costs of operation, and provide safety risks. EggSync 360 responds directly to these restrictions in the form of automatic sensing, automatic feedback control and multi-parameter environmental balancing.

### **1.1.3 Purpose and Justification**

The main aim of the EggSync 360 is to create and introduce an entirely automated, generalized incubation system that has the ability to perform better than the traditional and already existing systems. The system offers:

- Higher hatching accuracy
- On line decision-making based on sensor feedback.
- Remote monitored access and availability.
- Greater protection and stability.
- Less manual work and labor, less complexity.

The technology employed in this project has a great contribution as it integrates embedded systems, IoT, physics-based airflow design, and agricultural automation on the same platform.

### **1.1.4 Scope**

The project aims at designing and putting into practice:

- Full environment of incubation with controlled temperature, humidity and air-quality.
- Automation and wireless monitoring system based on ESP32.
- Multi-species Multi-species support with automatic configuration.
- UV sterilization, HEPA filtration, oxygen control and removal of harmful gases.
- Mobile based and real time notification system.
- independent control Dual-chamber structure (setter and hatcher)
- Solar, UPS and IPS compatible energy efficient architecture.

Hardware design, software integration, testing, documentation and performance evaluation are also included in the scope.

## **1.2 Project Planning and Initiation**

### **Feasibility Study (Step-by-Step)**

#### **Phase 1: Preliminary Analysis & Project Scope Definition**

The first stage was the definition of the scope of the solution needed and the limitations of current incubation systems and the identification of the scope of the solution, which would affect automation, high-accuracy sensing, safety features, and an IoT-based monitoring system. The analysis has established the need to have an all-in-one incubator that could accommodate different types of eggs and automatically maintain the right environmental conditions.

## **Phase 2: Market Feasibility Analysis**

The market research suggested that there was an increasing demand of smart incubation in the poultry farms, commercial hatcheries, agricultural programs in rural areas and research centers. EggSync 360 is commercially viable because of its growing use of automation and its necessity of high hatching reliability. The current industrial incubators tend to be expensive and do not have advanced technology like the IoT monitoring and gas control, which presents an obvious market opportunity.

## **Phase 3: Technical Feasibility Analysis**

It has been established through technical analysis that the ESP32 microcontroller, paired with a variety of sensing devices, such as temperature, humidity, oxygen, CO<sub>2</sub>, and airflow, can be used to achieve the necessary automation. Hardware integration is based on the compatibility of heating modules, cooling systems, UV sterilization, and HEPA filters. It can also be monitored wirelessly by having inbuilt Wi-Fi and support of cloud based server.

## **Phase 4: Financial Feasibility Analysis**

Preliminary cost analysis indicates that EggSync 360 can be designed at a much lower cost than commercial industrial incubators but with a better functionality. The modular design saves on maintenance costs and is upgradeable. The financial feasibility of the project is both in prototyping and in case of commercialization.

### **1.3 Target User Profile and Tentative Elicitation Process**

#### **1.3.1 Target User**

- Poultry farm owners.
- Hatcheries Commercial operators.
- Research laboratories.
- Institutions of agricultural technology.
- Massive poultry manufacturers.
- Small medium rural farmers.
- Technical students and researchers.

#### **1.3.2 User profile**

Table 1.1: User Profile for Poultry Farm Owner

<b>User Class</b>	<b>Note on Characteristics</b>
Type of user	Farm Owner / Small to Medium Poultry Business Operator
Age range	20–65 years

Frequency of use	Daily use during incubation cycles
Mandatory	Yes
Computer experience	Basic to moderate
Education	Varies (Primary to Graduate)
goal	Achieve higher hatching rate with minimum manual effort
Language skills	Local language, basic English
Number of users	Many (varies by farm size)
Training	Short operational training required
Others system use	Traditional incubators
Way of working	Mostly manual or semi-automated tasks

Table 1.2: User Profile for Hatchery Technician

User Class	Note on Characteristics
Type of user	On-site hatchery worker / technician
Age range	20–45 years
Frequency of use	Multiple times throughout the day
Mandatory	Yes
Computer experience	Basic
Education	Technical/vocational background
goal	Monitor environment stability and ensure operational safety
Language skills	Local language
Number of users	Limited (1–3 per hatchery unit)
Training	Required for system operation & safety procedures
Others system use	Ventilation systems, small incubators
Way of working	Hands-on operational tasks

Table 1.3: User Profile for System Admin / Technical Operator

User Class	Note on Characteristics
Type of user	System Admin / Technical Manager
Age range	22–40 years
Frequency of use	Periodic use for configuration & maintenance
Mandatory	Yes

Computer experience	High
Education	Diploma or B.Sc in technical field
goal	Configure egg profiles, calibrate sensors, maintain system health
Language skills	English and local language
Number of users	Very few (1–2 at most)
Training	Advanced technical training
Others system use	Servers, network systems, monitoring dashboards
Way of working	Highly systematic and data-driven

Table 1.4: User Profile for Researcher / Agricultural Scientist

User Class	Note on Characteristics
Type of user	Researcher / Scientist / Academic Staff
Age range	25–60 years
Frequency of use	Intermittent (during experiments)
Mandatory	No (optional, based on project)
Computer experience	High
Education	Graduate/Master’s/PhD level
goal	Data analysis, experimental incubation, species-specific studies
Language skills	Strong English proficiency
Number of users	Few (per institute/project)
Training	Minimal training required
Others system use	Research tools, analytics software, IoT devices
Way of working	Structured, experimental, analytical

### 1.3.3 Elicitation Process

The following were used in the process of collecting user requirements:

- **Poultry farm owners** will be interviewed to determine viable issues.
- **Observation in the hatcheries** of the area to examine temperature and humidity imbalance.
- **Questionnaires to assess the features** that are desired like real-time monitoring.

- **Professional advice of the agricultural specialists** concerning the species-specific demands.
- **Prototype demonstration** to optimize system behavior.

This mix has seen the system fulfill the requirements of both the technical users and the non-technical users.

## 1.4 Project Block Diagram

**Project Block Diagram of Smart Universal Automated Incubator System (EggSync 360)**

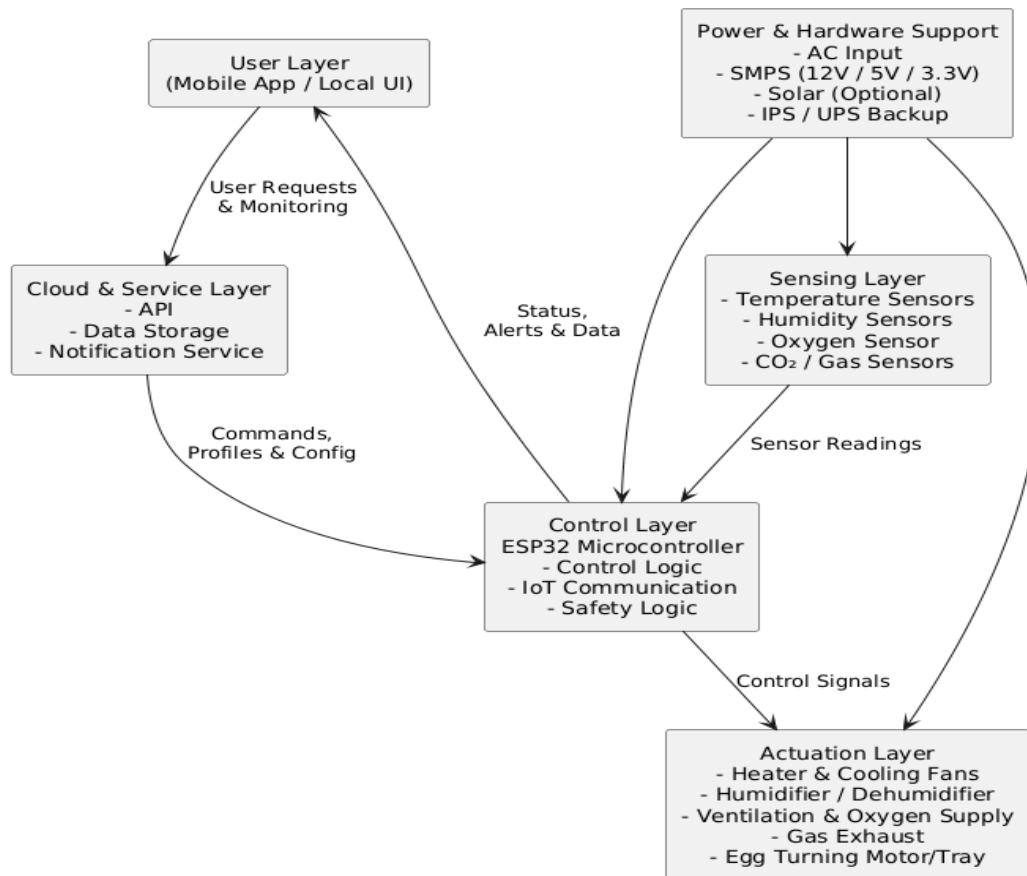


Figure 1.1: System Block Diagram

### System Block Diagram Description

The Smart Universal Automated Incubator System (EggSync 360) system block diagram shows the entire architecture and operations flow of all the key hardware and software components. The diagram has three main layers which include the layer of user and cloud interface, the main controller and the hardware module layers.

At the top, there is Mobile Application, which gives users an opportunity of remotely viewing real-time incubation information, notifications, settings, and egg type choices. Any message between the mobile interface and the device is transited via the Cloud Server that logs data, user accounts and system activity. The cloud then directly communicates with the central controller in order to synchronize commands and environmental data.

The ESP32 Microcontroller serves as the central body of the system as a controlling unit. It receives sensor input, runs the control algorithms, controls the IoT communications, provides safety logic and controls the environmental regulation mechanisms. The ESP32 would be in contact with the entire sensing modules and actuator units so that the incubator is accurately controlled. The controller also controls the Egg Turning Logic that moves the automatic egg turning motor/ tray system based on species-specific needs.

Multi-zone temperature sensors and multi-zone humidity sensors, oxygen level sensors, CO<sub>2</sub> and harmful gas sensors, airflow sensors, and ambient external sensor make up the Sensing Modules on the hardware side. These sensors keep giving real-time feedback to the ESP32 as the conditions in the incubation should remain optimal.

The heating chamber, cooling and ventilation fans, humidifier and dehumidifier units, oxygen supply module, the gas exhaust system, UV sterilizer, and the automatic egg turning motor/tray mechanism are all the Actuator Modules. The ESP32 directly controls each actuator through sensor readings and incubation profiles.

The Power Management System will provide regulated voltages (220 V, 12 V, 5 V, 3.3 V) of the AC input, optional solar and IPS/UPS backup, so that the power will be continuously available. The controller, sensors, actuators, and local user interface are given power.

Lastly, the Local User Interface has two digital displays (one dedicated to setter unit and the other to the hatcher unit) and the buzzer and status indicators which means that it can monitor in-device and issue alerts without having to use the mobile app.

In general, the block diagram illustrates how the EggSync 360 will be a system integrating a smart sensing system, precision control, automated egg turning, air quality control, power control, and automated cloud-based monitoring into a single intelligent incubation platform.

## **1.5 System Requirements**

### **1.5.1 Hardware Requirements**

- ESP32 microcontroller
- Humidity sensors (various zones) Temperature sensors.
- Oxygen and CO<sub>2</sub> gas sensors
- Air fans and air circulation modules.
- Heating coils and heating chamber.
- Ventilation motors and cooling system motors.
- UV sterilization module
- HEPA filtration unit
- Display panel, control buttons.
- Power supply, Solar/IPS/UPS support.

### 1.5.2 Software Requirements

- Arduino IDE / PlatformIO
- ESP32 firmware (C++)
- Cloud server / Mobile application platform.
- Data visualization tools
- Notification APIs
- Version control system

### 1.5.3 Constraints and Dependencies

- The availability of hardware components.
- Precision of sensors calibration.
- The internet connection should be stable to allow real-time monitoring.
- Constant incubation power reliability.
- Environment (temperature changes, humidity changes).

## 1.6 Project Scheduling

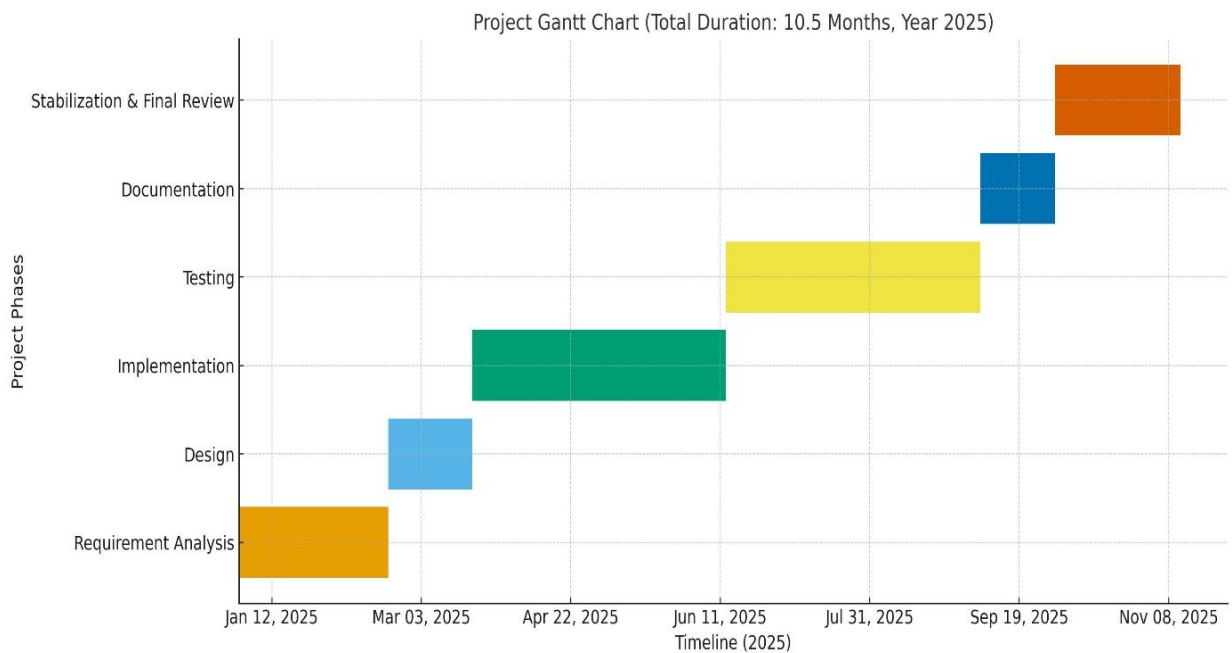


Figure 1.2: Gantt Chart for project schedule

**Table 1.5: Duration Breakdown Included in This Chart**

<b>Phase</b>	<b>Duration</b>
<b>Requirement Analysis</b>	1 month 20 days ( $\approx$ 50 days)
<b>Design</b>	28 days
<b>Implementation</b>	2 months 25 days ( $\approx$ 85 days)
<b>Testing</b>	2 months 25 days ( $\approx$ 85 days)
<b>Documentation</b>	25 days
<b>Stabilization &amp; Final Review</b>	42 days ( <i>added to complete 10.5 months total</i> )

**Total duration  $\approx$  315 days = 10.5 months**

The Gantt chart is the graph that visually displays the entire development timeline of the Smart Universal Automated Incubator System (EggSync 360) (10.5 months) with the phases of every project step being illustrated by a particular color to be able to understand the project development timeline visually.

The **Requirement Analysis** phase indicated in **blue** takes 20 days and 1 month, and provides a good grasp of what is needed, what is possible, and system constraints.

The **Design**, as shown in **purple** takes 28 days and involves architectural planning, hardware software integration design, and workflow modeling.

The stage of **Implementation**, which is marked by **green** color lasts 2 months and 25 days and comprises hardware assembly, circuit development, firmware programming and IoT integration.

**Testing** phase highlighted in **orange** also takes 2 months and 25 days, which is dedicated to functional testing, environmental stability test, calibration, and long term performance verification.

Lastly, the **Documentation** phase, which is denoted by **yellow** color, takes 25 days and includes preparation of the project report, project diagrams, project user manual, as well as the final project academic deliverables.

The last stage is the **Stabilization and Final Review stage**, which is shown in **red** and takes 42 days to make last-minute refinements, ascertain reliability, and make the system completely ready to be submitted and demonstrated.

These color-coded sections combined visibly demonstrate the chronological step-by-step process of the workflow and the time-investment needed to accomplish the EggSync 360 project.

## **1.7 Summary**

In this chapter, I presented the objective, history and general importance of the Smart Universal Automated Incubator System (EggSync 360). It gave a description of the scope of the project, feasibility study, identification of the users, as well as the requirement-gathering techniques. The chapter provides the groundwork upon which one can see how the system will combine the automation, sensor technology, and IoT capabilities to overcome the drawbacks of the traditional incubators. The following chapter will outline the system functionality and non-functionality requirements, as well as its design, drawings and plans of implementation.

## CHAPTER 2

# DESIGN AND IMPLEMENTATION

### 2.1 Introduction

The chapter will give the design and implementation features of the Smart Universal Automated Incubator System (EggSync 360). It includes software and hardware design, functional and non-functional requirements, system design and a set of UML diagrams that demonstrate how the internal structure and workflow of the system work. This chapter aims at having a thorough insight into the working of the system, the interaction of various components of the system, and the automation of the system with sensor feedback, real time data processing, and IoT communication. The logical representation of this system, the use cases, the activity sequences, the class structure and the data modeling are also described in this chapter.

### 2.2 Functional Requirements

Functional requirements explain the essence of the activities that the EggSync 360 system has to carry out to be sure that automated incubation will take place.

<b>FR01</b>	<b>Egg Type Selection</b>
<b>Description</b>	The user selects the type of egg (e.g., chicken, duck, quail, turkey). The system automatically configures the required temperature, humidity, turning schedule, and incubation duration based on predefined profiles.
<b>Stakeholder</b>	User, System Admin

<b>FR02</b>	<b>Environmental Monitoring</b>
<b>Description</b>	The system must continuously read temperature, humidity, oxygen level, CO <sub>2</sub> level, and airflow status from multiple sensors distributed inside the chamber.
<b>Stakeholder</b>	System, User

<b>FR03</b>	<b>Automated Temperature Control</b>
<b>Description</b>	Based on sensor input, the system activates the heating chamber or cooling fans to maintain the required temperature within a precise tolerance range.

<b>Stakeholder</b>	System
--------------------	--------

<b>FR04</b>	<b>Humidity Regulation</b>
<b>Description</b>	The system automatically adjusts humidity through humidification/dehumidification to maintain optimal levels for the selected egg type.
<b>Stakeholder</b>	System

<b>FR05</b>	<b>Air Quality and Gas Control</b>
<b>Description</b>	If oxygen decreases below the threshold, the system enables oxygen supply. If harmful gases (CO <sub>2</sub> , NH <sub>3</sub> ) rise, the system activates ventilation and exhaust units.
<b>Stakeholder</b>	System

<b>FR06</b>	<b>UV Sterilization and Air Filtration</b>
<b>Description</b>	The system activates UV lights for sterilization and uses HEPA filters to ensure clean airflow inside the incubator.
<b>Stakeholder</b>	System, User

<b>FR07</b>	<b>Real-Time Monitoring &amp; Notifications</b>
<b>Description</b>	Users will receive real-time alerts related to temperature deviation, humidity imbalance, gas issues, candling schedule, or hatching time via a mobile application.
<b>Stakeholder</b>	User

<b>FR08</b>	<b>System Dashboard (Mobile App)</b>
<b>Description</b>	The user can view live data, charts, egg progress timeline, current environmental status, and system logs.
<b>Stakeholder</b>	User

<b>FR09</b>	<b>Safety Shutdown Mechanism</b>
<b>Description</b>	The system must automatically shut down heaters or activate rapid

	ventilation if critical safety thresholds are exceeded.
<b>Stakeholder</b>	System

<b>FR10</b>	<b>Data Logging</b>
<b>Description</b>	The system continuously stores sensor readings and system activities for monitoring, analysis, and debugging.
<b>Stakeholder</b>	System, User

## 2.3 Non-Functional Requirements

Non-functional requirements ensure that the system performs efficiently, reliably, and safely.

### 2.3.1 Performance

- The system has to refresh all the sensor data at a rate of 1-3 seconds.
- The temperature should not be allowed to exceed  $\pm 0.3\text{degC}$ .
- The mobile application should display real-time information with not more than a delay of less than 1 second (internet-dependent).

### 2.3.2 Reliability

- The system should operate 24 hrs. throughout the period of incubation.
- The fail-safes should be induced when there is overheating, sensor fault or an imbalance of gas.
- Multiple temperature and humidity sensors in various areas make sure that this is done.

### 2.3.3 Portability

- Its firmware can be transferred to other ESP32 variants or other IoT microcontrollers.
- The system is adaptable to other sizes of incubators or species of eggs.

### Additional Non-Functional Requirements (for better quality)

- ❖ **Security:** The mobile dashboard can be accessed by authorized users.
- ❖ **Usability:** The mobile application should be easy and user-friendly to farmers.
- ❖ **Scalability:** The system can be increased by an additional number of sensors or by an addition of the chambers.
- ❖ **Maintainability:** Layout Hardware layout and modular firmware design: easily upgradeable.

## 2.4 Object-oriented System design using UML

### 2.4.1 Use Case Diagram

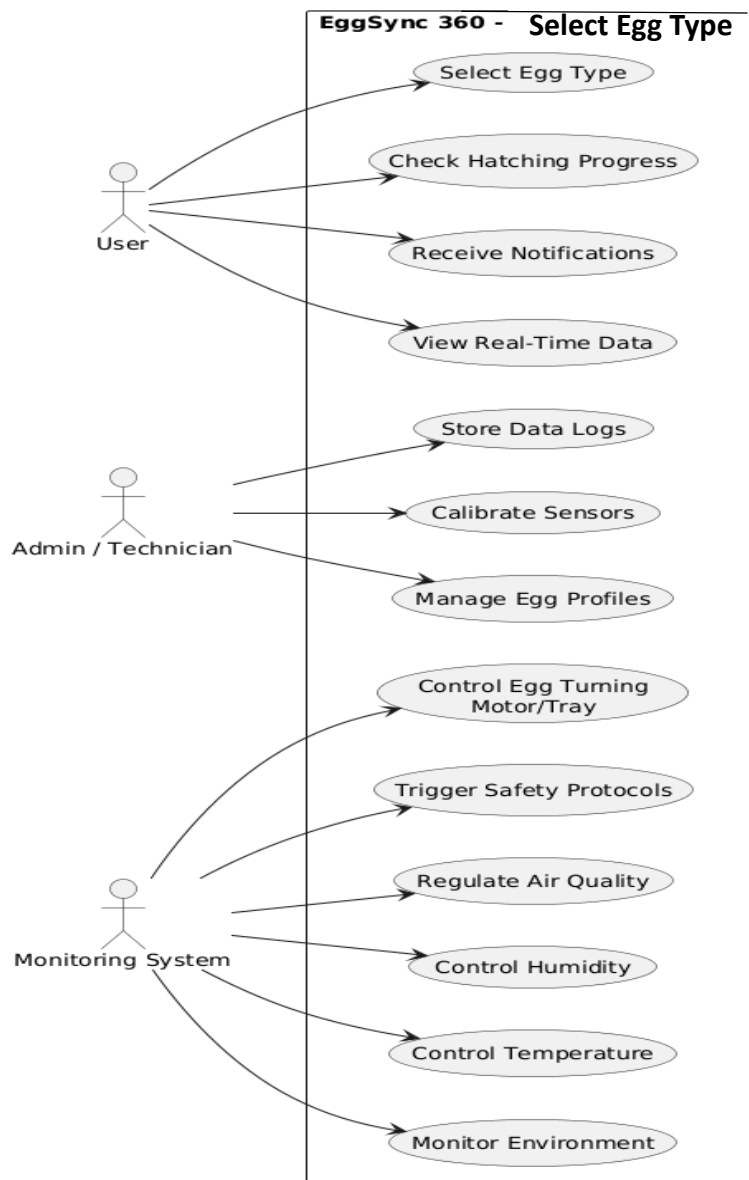


Figure 2.1: Use case Diagram for Select Egg Type

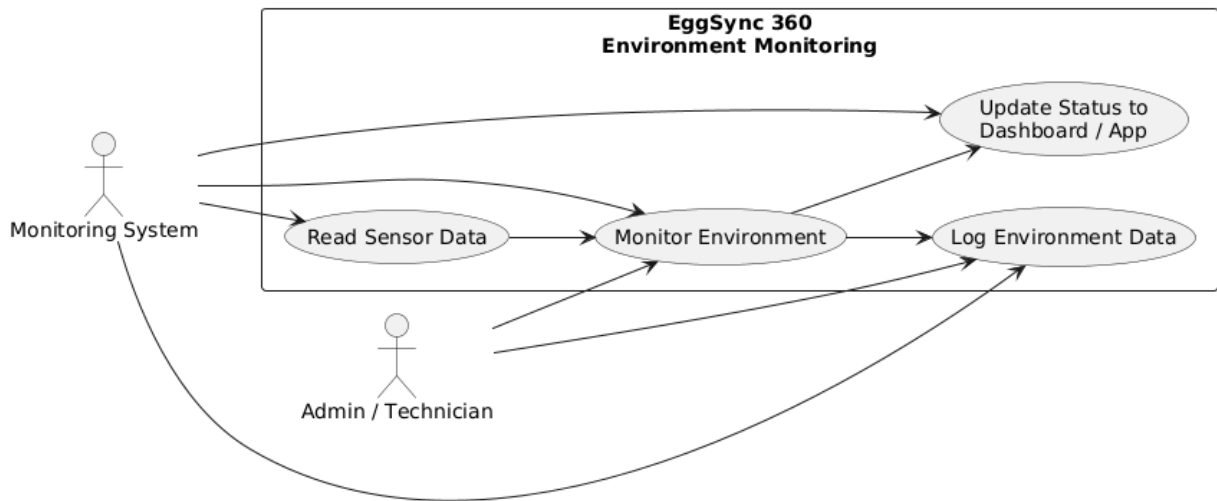


Figure 2.2: Use case Diagram for Environment Monitoring

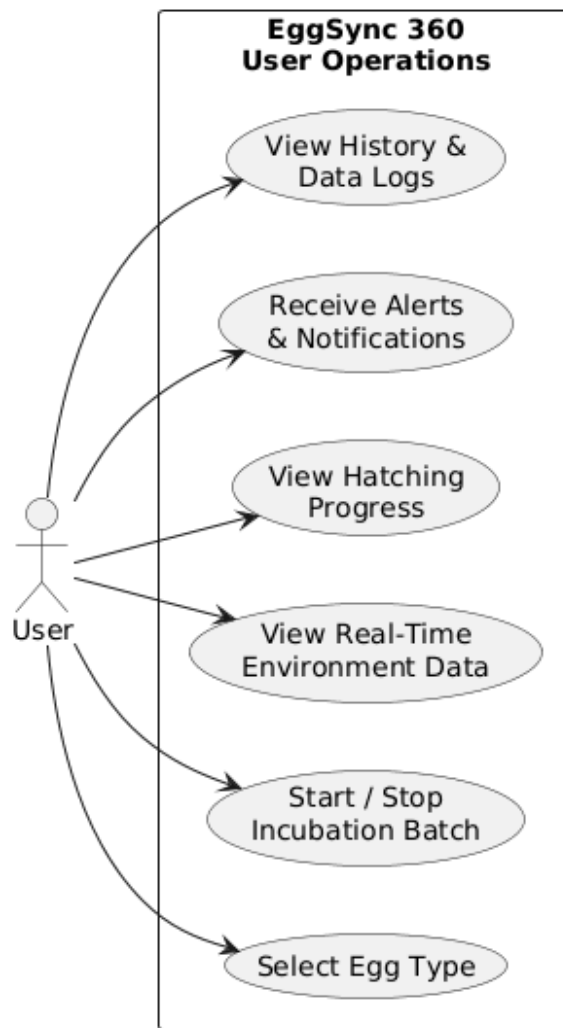


Figure 2.3: Use case Diagram for User Operation

## 2.4.2 Case Description

Table 2.1: Case Description-01: Select Egg Type

Use Case	Select Egg Type
Actor	User
Brief Description	The user chooses one of the types of eggs (e.g. chicken or duck or quail or turkey) in the mobile application to run the system automatically according to some predetermined incubation parameters.
Precondition	The system is active and the mobile application is linked and the user has been authenticated.
Post condition	The system enters the values of temperature, humidity, turning cycle and length of time that are species specific into the controller.
Main Success Scenario	<ol style="list-style-type: none"> <li>1. EggSync 360 mobile app is opened by the user.</li> <li>2. User goes to egg selection menu.</li> <li>3. User chooses a certain species of eggs.</li> <li>4. The system retrieves incubation parameters which are predefined.</li> <li>5. All settings of the environment are automatically updated in ESP32.</li> <li>6. The user is presented with a confirmation message.</li> </ol>
Alternative Flow	<ul style="list-style-type: none"> <li>• In case the internet is not available - the system loads default offline profiles.</li> <li>• In case of corruption of profile data - profile load error message.</li> <li>• In case sensors are not prepared - "Sensor Calibration Required."</li> </ul>
Exception Flow	<ul style="list-style-type: none"> <li>• During configuration, App disconnects with device.</li> <li>• Selection of invalid types of eggs or an incomplete profile data.</li> </ul>
Stakeholders	User, System

Table 2.2: Case Description 2: Monitor Environment

Use Case	Monitor Environment
Actor	Monitoring System (Automated System)
Brief Description	The system will constantly measure temperature, humidity and oxygen, CO 2, and air flow, and the general environment inside the incubator.
Precondition	Sensors are adjusted and attached to ESP32 microcontroller.
Post condition	All environmental data is stored and actuator control logic is updated as well.
Main Success Scenario	<ol style="list-style-type: none"> <li>1. System retrieves data on all environmental sensors.</li> <li>2. ESP32 processes sensor data.</li> <li>3. The information is recorded in internal memory and transferred to the cloud.</li> <li>4. Actuators regulate the amount of heat, humidity, ventilation, and oxygen according to the readings.</li> <li>5. This monitoring is continually passed on in system.</li> </ol>
Alternative Flow	<ul style="list-style-type: none"> <li>• Outputs that are not evenly measured by the sensor - system repeats reading and raises warning.</li> <li>• In case of cloud connection failure - logging goes offline.</li> </ul>
Exception Flow	<ul style="list-style-type: none"> <li>• Sensor hardware failure.</li> <li>• Environment and extreme out-of-range triggers emergency protocol.</li> </ul>
Stakeholders	System, Admin/Technician

Table 2.3: Case Description 3: User Operations

Use Case	User Operations
Actor	User
Brief Description	This use case outlines all the significant interactions that a user will carry out with the EggSync 360 system such as choosing the type of egg, incubation, environment data, progress monitoring, receiving alerts and viewing historical logs.
Precondition	The system has to be started and the user has to be authenticated with the help of the mobile app or the local interface.
Post condition	System loads the settings, which have been chosen by the user, shows the updated information, and records all the activities of the user.
Main Success Scenario	<ol style="list-style-type: none"> <li>1. The EggSync 360 interface is opened by the user.</li> <li>2. User selects the egg type.</li> <li>3. Incubation batch is initiated by the user.</li> <li>4. System shows real-time information and progress.</li> <li>5. User will get notification regarding critical events.</li> <li>6. User sees history and records where necessary.</li> </ol>
Alternative Flow	<ul style="list-style-type: none"> <li>• In case of no network connection - System is in the offline mode.</li> <li>• In the event that invalid type of egg is chosen - System displays error message invalid selection.</li> <li>• In case of sensors being not calibrated - System indicates calibration need.</li> </ul>
Exception Flow	<ul style="list-style-type: none"> <li>• Application and user disconnection automatically.</li> <li>• System fails to start user settings.</li> <li>• Critical system error: displayed data. Protocol is not shown.</li> </ul>
Stakeholders	User, Admin/Technician, System

## 2.4.3 Activity Diagram

Activity Diagram - Full Incubation Process (EggSync 360)

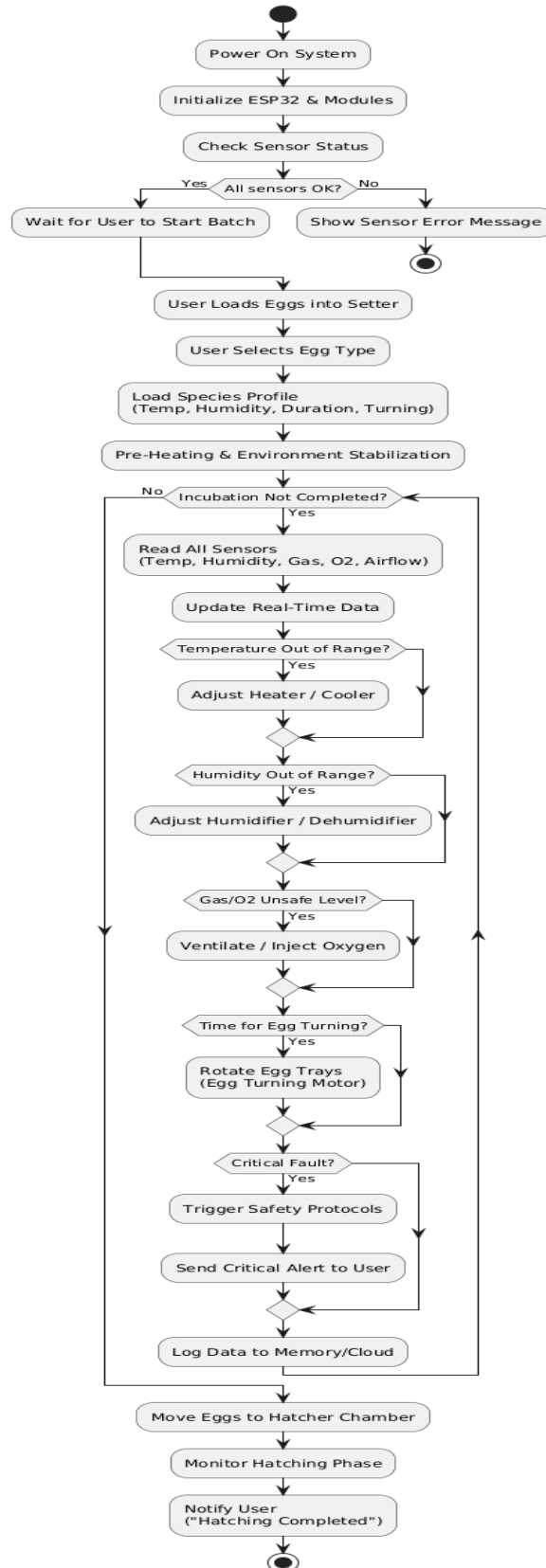


Figure 2.4: Activity Diagram for Full Incubation Process

**Activity Diagram - User Operation (Select Egg Type & Start Batch)**

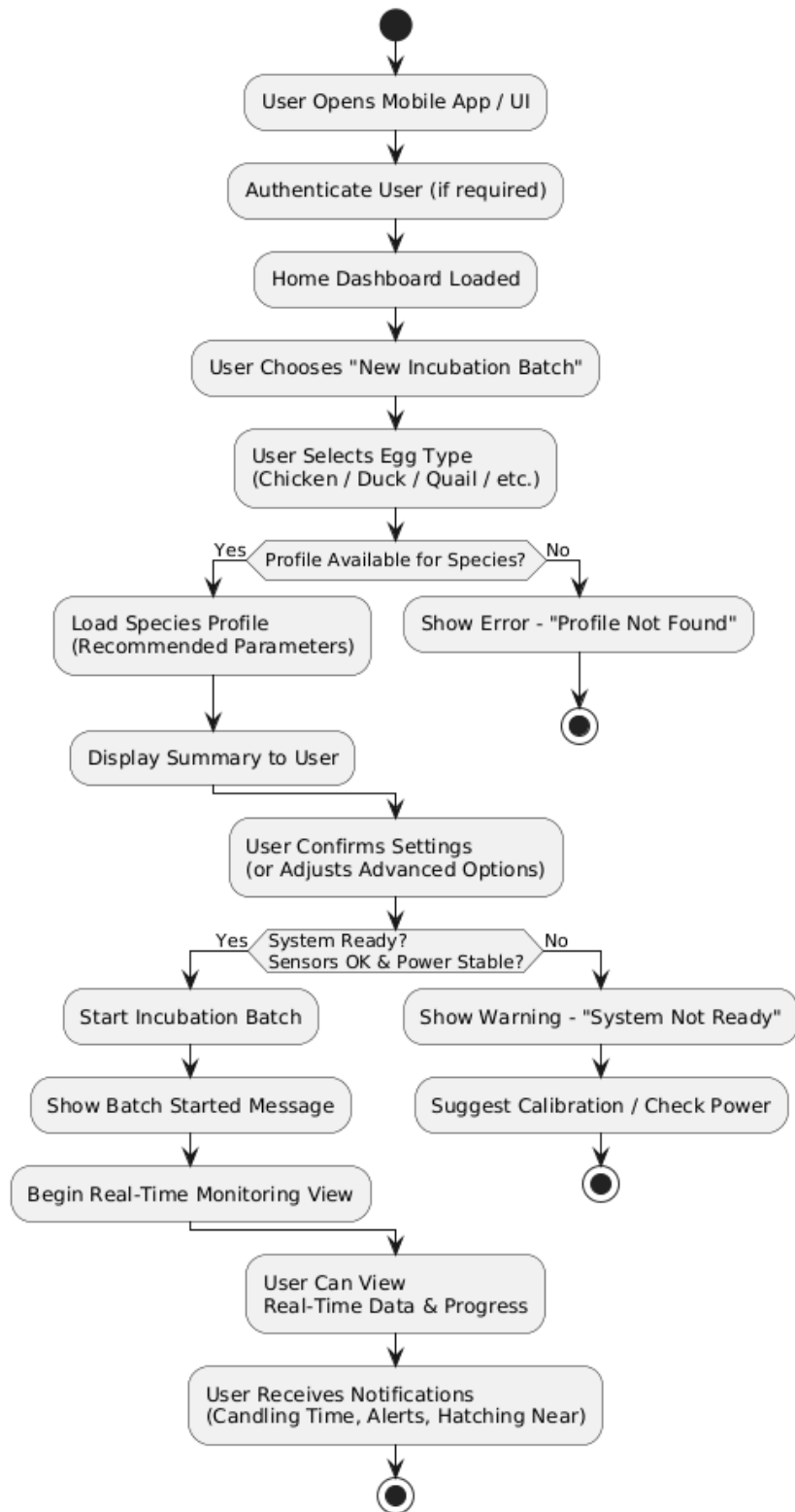


Figure 2.5: Activity Diagram for User Operation

**Activity Diagram - Environment Monitoring & Safety Control**

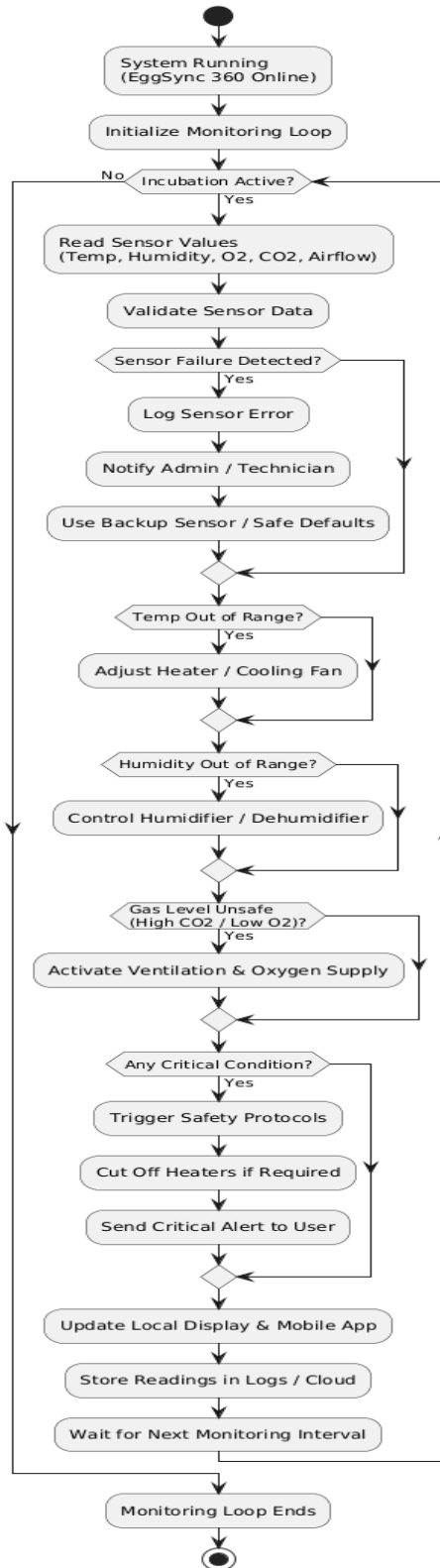


Figure 2.5: Activity Diagram for Monitoring and safety control

### **Activity Diagram 1 Description – Full Incubation Process**

This activity diagram is used to show the entire working process of the Smart Universal Automated Incubator System (EggSync 360) through a complete incubation process. It is initiated by the system startup, verification of the sensor and choice of the egg type by the user. After loading the species profile, the system enters into an endless monitoring cycle during which the temperature, humidity, air quality, oxygen level and gas concentration are constantly measured and analyzed. Sensors make the controller alter actuators which include heater, cooler, humidifier, ventilation fans, oxygen supply and egg-turning motor depending on sensor readings. The cycle has safety checks, and abnormal conditions or critical faults are detected. The system records and ensures that the environment is stable until the incubation period is over after which they are transferred to the hatcher and the user is informed of being done. This illustration is the entire automated control and feedback mechanism which is to provide optimum hatching conditions.

### **Activity Diagram 2 Description – User Operation (Select Egg Type & Start Batch)**

The workflow presented in this activity diagram is the user activity triggered by a new incubation batch in EggSync 360. It starts when the user opens the mobile application or the local interface and opens the incubation menu. Once the type of egg has been chosen, the system will retrieve the profile of the species and show recommended parameters. The settings can be confirmed or changed by the user prior to the beginning of the batch. The system ensures that it is ready to work by ensuring that the sensors have been calibrated, that power is stable, and that it is operational. In case all conditions are satisfied, an incubation batch is started and real time monitoring is initiated. During the activity, the user will see the live environmental information, monitor the progress, and get alerts about important events, candling, and hatching. This diagram draws attention to the interaction flow between the user and the system, as well as dynamic reaction of the system to actions set by the user.

### **Activity Diagram 3 Description – Environment Monitoring & Safety Control**

This activity diagram presents the automated workflow of monitoring and safety management of the environment done by EggSync 360. Incubation involves the system reading all the environmental sensors every minute such as temperature, humidity, oxygen, carbon dioxide, and airflow. The controller authenticates sensor data and reacts to the deviation by regulating heaters, coolers, humidifiers, and ventilation. The safety mechanisms are triggered when high concentration of dangerous gases, critical temperatures, and sensor malfunctions are detected. When this occurs, the system initiates emergency measures, i.e., deactivating heaters or forced ventilation in case, at the same time giving the user or the technician a notification. All readings will be captured locally and uploaded to the cloud, which will be fully traceable. The loop is repeated with constant intervals which is the repeated attempt of the system to create stable and safe conditions of incubation.

## 2.4.4 Sequence Diagram

### Sequence Diagram - Select Egg Type

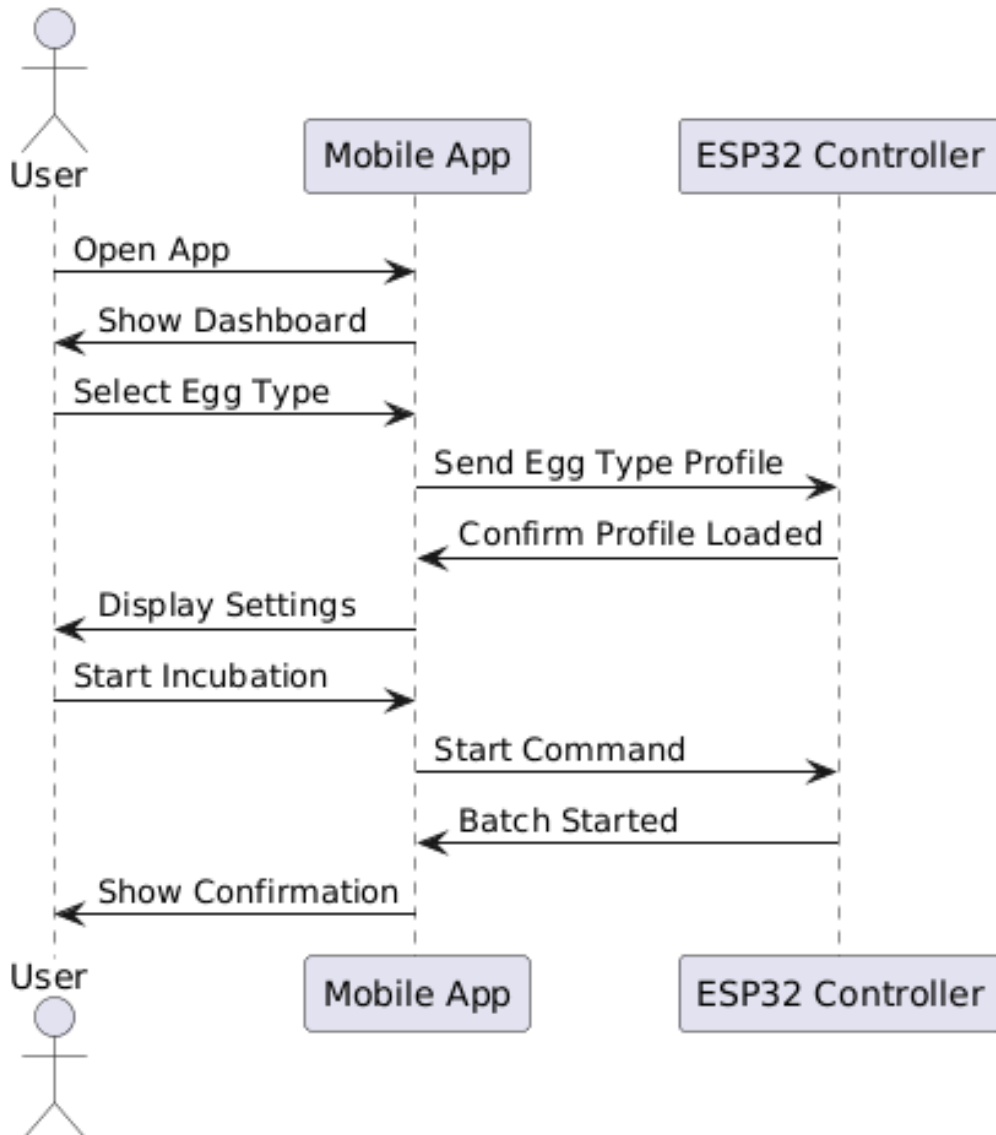


Figure 2.6: Sequence Diagram for Select Egg Type

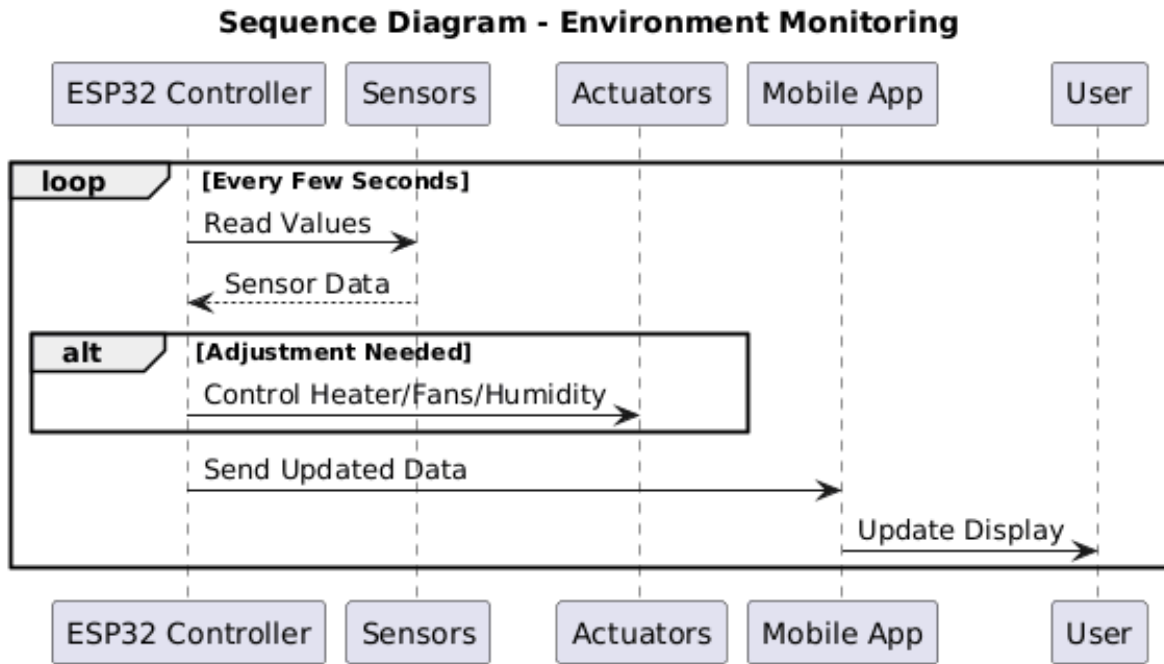


Figure 2.7: Sequence Diagram for Environment Monitoring

### Sequence Diagram 1 Description

This sequence diagram shows the communication between the user and mobile application with the ESP32 controller in the case of choosing an egg type and an incubation batch. With the mobile application, the user picks a species, and the profile of incubation is retrieved and transmitted to the controller. Once a confirmation is received, user incubates. The controller accepts the beginning of the batch and the application provides a confirmation message. This scheme indicates the key user-driven processes needed to initiate the incubation process.

### Sequence Diagram 2 Description

This sequence diagram shows the ongoing cycle of monitoring of the environment which is carried out by EggSync 360 system. The ESP32 controller reads the data of different sensors multiple times, analyzes the status of the environment, and activates the required changes using the actuators, including heaters, fans, and humidifiers. The latest information is then sent to the mobile application where the customer gets live readings. This diagram illustrates the feedback loop that is automated to provide stable conditions of incubation.

## 2.4.5 Class Diagram

**Class Diagram 1 - Core Control Structure of EggSync 360**

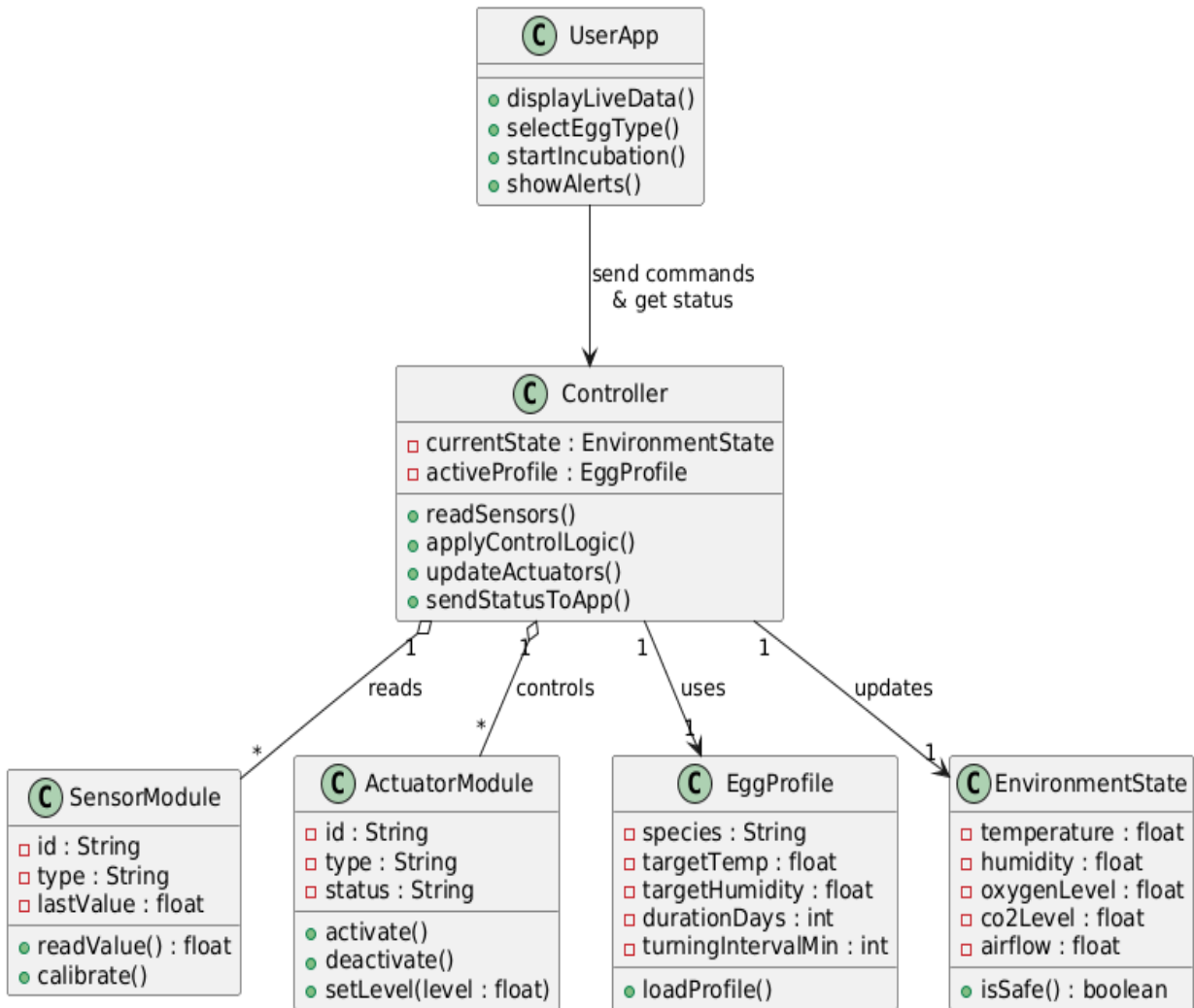


Figure 2.8: Class Diagram for Core Control Structure

## Class Diagram 2 - User, Device, Batch and Logging Model

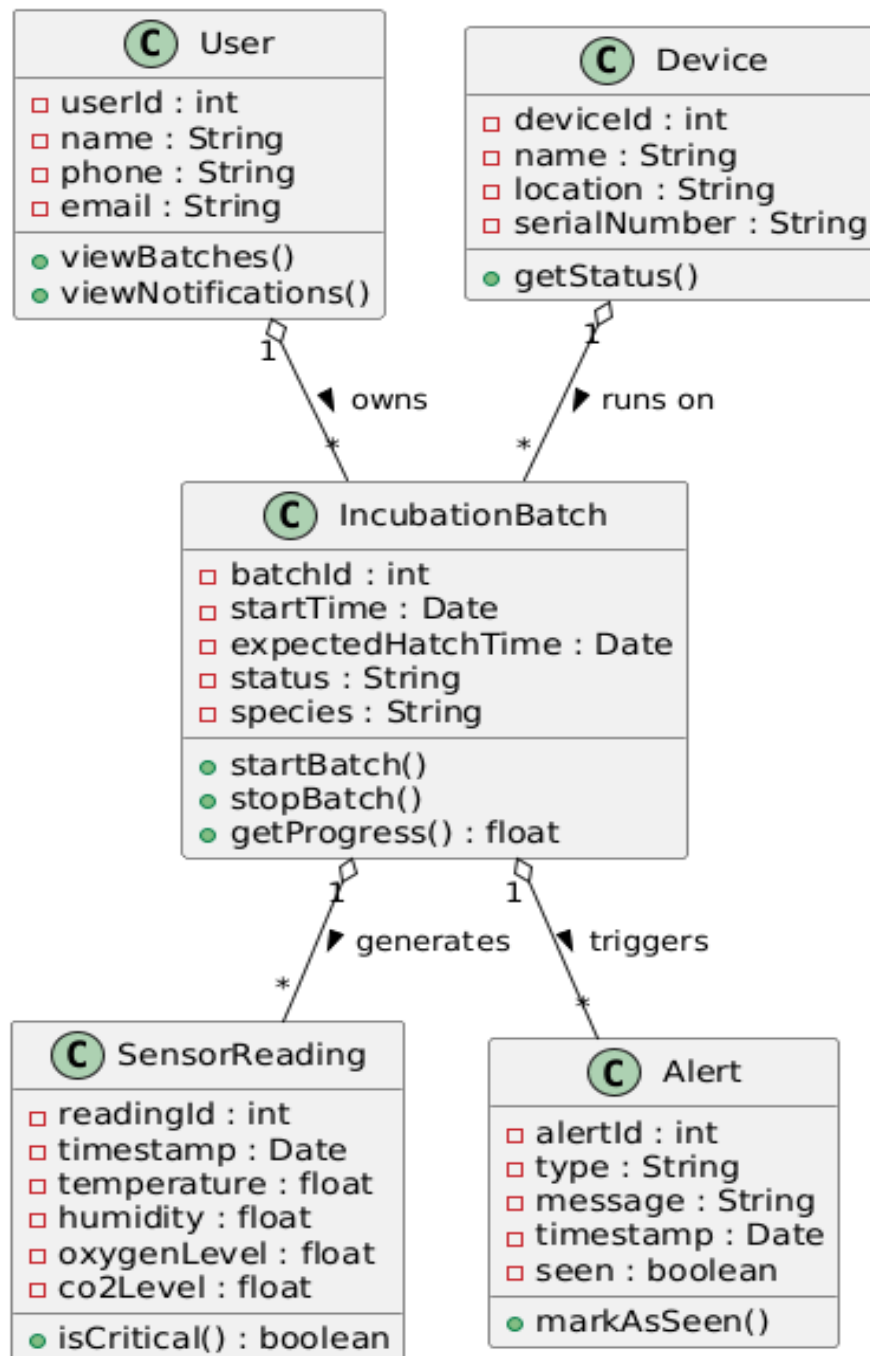


Figure 2.9: Class Diagram for User, Device, Batch and Logging Model

## 2.4.6 ER Diagram

ER Diagram 1 - Core Data Model of EggSync 360

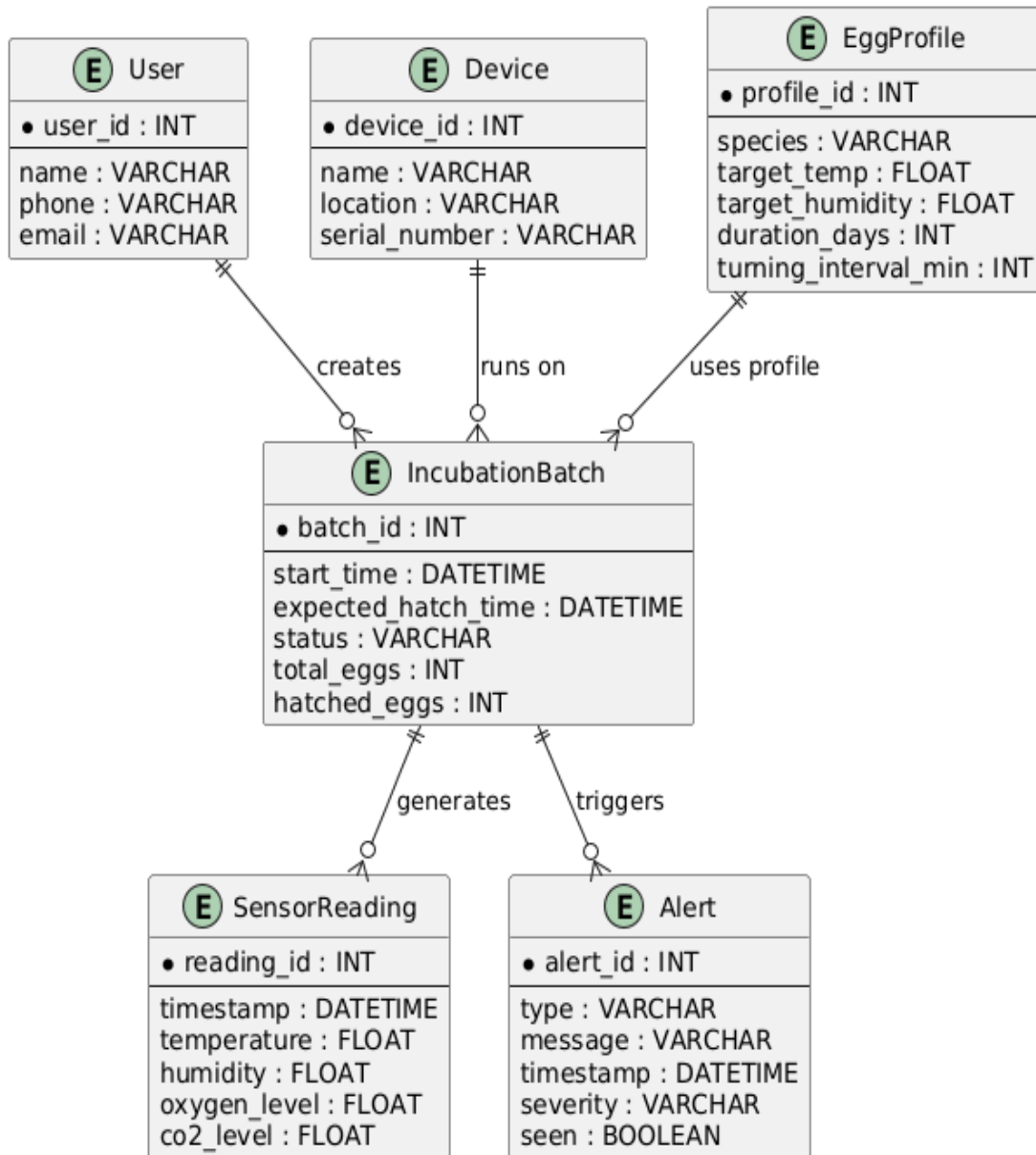


Figure 2.10: ER Diagram for Core Data Model

ER Diagram 2 - Environment & Hardware Mapping

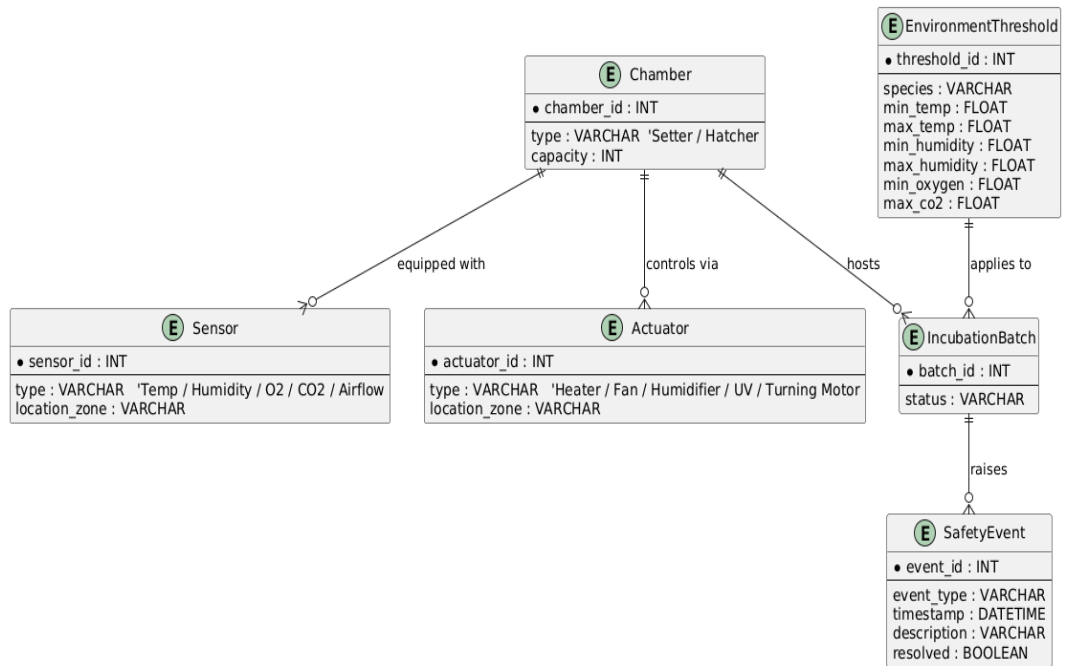


Figure 2.11: ER Diagram for Environment and Hardware Mapping

## 2.5 Coding: Appendix A

### Appendix A: Source Code Documentation

#### A.1 ESP32 Firmware Core

##### Content:

- Main control loop
- Sensor reading logic
- PID or set point temperature/humidity control.
- Egg turning logic

Safety interrupts **Language:** C++

##### Example Heading:

```

/* Appendix A.1 - ESP32
Firmware Core */
void loop() {
    readSensors();
    controlActuators();
    manageEggTurning();
    checkAlerts();
}
    
```

Appendix A.1 ESP32 Firmware Core

## A.2 Sensor Interface Module

### Content:

- DHT22/SHT31 drivers
- MQ/O<sub>2</sub>/CO<sub>2</sub> sensor reading
- Calibration formulas
- Error-handling routines

Language: C++

### Example Heading:

```
/* Appendix A.2 – Sensor
Interface */

float readOxygenSensor()
{
    return
    analogRead(o2Pin) *
    calibrationFactor;
}
```

Appendix A.2 Sensor Interface Module

## A.3 Actuator Control Module

### Content:

- Heater control
- Fan speed control
- Humidifier activation
- Oxygen valve
- Exhaust fan
- UV sterilizer
- Motor/servo turning system

Language: C++

### Example Heading:

```
/* Appendix A.3 –
Actuator Control */

if (temp < setTemp)
heater.on();

else heater.off();
```

Appendix A.3 Actuator Control Module

## A.4 Communication Module

### Content:

- WiFi connection setup
- MQTT publish/subscribe
- HTTP GET/POST
- Cloud server sync
- Error recovery

**Language:** C++

### Example Heading:

```
/* Appendix A.4 –  
Communication Module */  
  
mqttClient.publish("eggsy  
nc/data", jsonData);
```

Appendix A.4 Communication Module

## A.5 Mobile App Interface

### Content:

- Live dashboard UI
- Real-time sensor graphs
- Push notifications
- Batch management screen
- Egg type selection

**Language:**

- Dart/Flutter

### Example Heading:

```
/* Appendix A.5 – Mobile  
App Interface */  
  
Text ("Temperature:  
${data.temp} °C");
```

Appendix A.5 Mobile App Interface

## A.6 Cloud/Backend Scripts

### Content:

- API Endpoints
- Sensor data logging
- Hatch cycle management
- Notification triggers
- Database CRUD

### Language:

- Node.js

#### Example Heading:

```
/* Appendix A.6 – Backend Script */  
app.post("/update", (req, res) => {  
    saveToDB(req.body);  
    triggerNotifications(req.body);  
});
```

### Appendix A.6 Cloud/Backend Scripts

The Smart Universal Automated Incubator System (EggSync 360) implementation process is executed through a modular coding method with the aim of improving readability, maintainability and scalability. The ESP32 microcontroller core firmware is created in C++, and the primary functions of this firmware are sensor data processing, control algorithms, safety regulation processing, egg turns schedules, and data transmission to the cloud and mobile app.

The software modules are distributed in distinct modules like sensor handling, actuator control, communication, data logging and user interaction. Each of the modules is also introduced as a unique unit that communicates with the rest via well-familiar interfaces. This modular design facilitates the debugging and/or later extension or modification of individual components of the system without the rest of the codebase being affected.

Besides the firmware, the system has a mobile application interface, real-time monitoring, data visualization, and notification scripts/services at the cloud. These modules are connected to the ESP32 via typical IoT protocols (like HTTP or MQTT), and their specifics of implementation are also presented in the listings of the source code.

To maintain the brevity of the report and ensure the clarity of the information, the entire source code of the system is given in **Appendix A**. Appropriate and commented code blocks are given in the appendix in categories based on functionality.

**Table 2.4: Summary of Source Code Components Referenced in Appendix A**

Module Name	Description	Language	Appendix Reference
ESP32 Firmware Core	Main control loop, sensor reading, actuator control, egg turning logic	C++	Appendix A.1
Sensor Interface Module	Drivers and functions for temperature, humidity, oxygen, and gas sensors	C++	Appendix A.2
Actuator Control Module	Control routines for heater, fans, humidifier, oxygen valve, exhaust, UV, and motor	C++	Appendix A.3
Communication Module	WiFi setup, MQTT/HTTP communication, cloud data exchange	C++	Appendix A.4
Mobile App Interface	Screens for live data, alerts, and batch control	e.g., Dart/Flutter or Java/Kotlin (as implemented)	Appendix A.5
Cloud/Backend Scripts	APIs, logging services, and notification handlers	e.g., Node.js/PHP/Python	Appendix A.6

## 2.6 Summary

In this chapter the entire design and implementation information of the Smart Universal Automated Incubator System (EggSync 360) were given. It started by establishing the functional and non-functional requirement that establish the scope, performance expectation, reliability requirement, and restrictions of the system. This was followed by a description of the architecture of the system using several UML diagrams of the use case diagrams, activity diagrams, sequence diagrams, class diagrams, and entity-relationship diagrams. The models provided insight into the relationship between the users, the system components, the data entities, and the internal control processes.

The block diagram, circuit diagram, wiring diagram, and software architecture diagram were also given in the chapter to show the general integration of hardware and firmware. The microcontroller ESP32 as the central processing unit was highlighted to illustrate how the sensor data is collected, actuator responses are driven, the egg turning cycles, temperature and humidity are controlled, the air quality is monitored and communication with the cloud and mobile application is coordinated. Other hardware components: heater, cooling fan, humidifier, oxygen supply unit, exhaust unit, UV sterilization, multi-zone sensor network was also discussed vis-a-vis the related control logic.

In addition, the chapter has pointed out the modular coding method and cited the entire source code presented in Appendix A. The design principles that are taken in this system make it accurate, safe, automated and hatch with high efficiency. In general, this chapter makes a clear picture of how EggSync 360 can be driven internally by the integrated set of hardware, software, and smart control algorithms.

## Chapter 3

### Software Testing

#### 3.1 Introduction

Software testing would be a necessary part of the development process with the Smart Universal Automated Incubator System (EggSync 360). This chapter aims at outlining the testing strategies, test cases, test execution procedures, and test results, which were employed to determine the functionality of the system to be correct, reliable, and perform at the required level. As EggSync 360 is a system that combines firmware, sensor modules, actuator drivers, IoT communication and mobile application modules, testing is conducted to ensure each module responds as intended in various environmental and operational situations.

The experimental procedures aim at testing the correctness of sensors, actuator behavior, temperature and humidity stability, real-time information transmission, safety features, connection to the cloud, information delivery to the notification, and the performance of the system in the case of the long incubation period. The design of each test case was guided by the functional requirements identified in Chapter 2 to ensure that it is fully covered and traced through all the features of the system.

In this chapter, the test plan, the nature of the testing to be conducted, documentation of test cases, and results that will make EggSync 360 ready to operate in the field have been presented.

#### 3.2 Testing Strategy

The EggSync 360 testing plan is based on an organized and multi-layered approach to test the behavior of software and hardware. The system has embedded firmware, IoT communication, real-time monitoring, and high-precision environmental control; hence, some testing methodologies were used:

##### 3.2.1 Unit Testing

Individual firmware modules were unit tested including:

- Sensor reading functions
- Generation and transformation of routines.
- Turning motor, humidifier, heater, fans, actuator control functions.
- Cloud API request handlers
- Internal safety-check works.

This was aimed at making the modules act properly under isolated conditions.

### **3.2.2 Integration Testing**

Integration testing verified the interaction between:

- ESP32 controller ↔ Sensors
- ESP32 controller ↔ Actuators
- ESP32 ↔ Cloud server
- Cloud server ↔ Mobile application

This verified entire data stream flow and provided proper implementation of control algorithms.

### **3.2.3 System Testing**

System testing was performed on the fully assembled incubator to verify:

- Temperature stability
- Humidity regulation
- Gas sensor behavior
- Automatic egg turning
- UV sterilization cycles
- Real-time mobile updates
- Safety protocol activation

This ensured the entire system met functional requirements.

### **3.2.4 Performance Testing**

Performance tests validated:

- Response time of sensors
- Actuator activation delay
- Data transmission speed to the cloud
- Mobile app notification latency
- Long-duration performance (continuous 24–48-hour stability tests)

These tests ensured high reliability.

### **3.2.5 Reliability & Stress Testing**

Stress testing included:

- Extreme temperature changes
- High humidity conditions
- Voltage fluctuation simulation
- Continuous operation across multiple days

This confirmed that EggSync 360 can handle real-world operational loads.

### **3.2.6 User Acceptance Testing (UAT)**

The final testing phase involved test execution by:

- A farm owner
- A technician
- A student operator

Feedback validated the usability, clarity of interface, notification accuracy, and system stability.

### **3.2.7 Power & Inverter Testing (Point-Based Format)**

To guarantee continuous work of EggSync 360 in the areas where electrical instability often appears, the experiment of power and inverter was postulated widely. Testing points that were decided to be major and evaluated included the following:

#### **• Power Interruption Test**

- Artificial intermittent power cut across the AC to confirm continuity of the system.
- The inverter was ensured to activate without a restart of the controller.
- Verified that there were no sensor modules that suddenly went dead.

#### **• Inverter Switching Delay Test**

- Ratings Time taken to switch to inverter when using AC power.
- Ensured that the heater, fans, humidifier, and the egg turning motor have been turned on during switching.
- Ensured that the ESP32 was not brown-out by ensuring that it remained stable at voltage.

#### **• Low Voltage Operation Test**

- Ratings Time taken to switch to inverter when using AC power.
- Ensured that the heater, fans, humidifier, and the egg turning motor have been turned on during switching.
- Ensured that the ESP32 was not brown-out by ensuring that it remained stable at voltage.

#### **• Load Handling and Stability Test**

- Assessed as an inverter capacity to maintain the load of a heater, the fan, the humidifier and the load of a motor in parallel.

- Confirmed that temperature and humidity did not fluctuate as a result of changes in power.

#### • **Recovery and Resynchronization Test**

- System behavior on restoration of power.
- Synchronized ensured controller, sensors, actuators and communication modules automatically.
- Both cloud connection and mobile alerts went back to normal.

#### • **Safety Mechanism Validation**

- Ensured that overheat was working as the inverter mode was switched on.
- Guaranteed emergency ventilation activation when there was no safe thermal condition even in unstable power situations.
- Denied that there was uncontrolled heating during power variation.

#### • **Data Integrity Test**

- Ensured that overheat was working as the inverter mode was switched on.
- Guaranteed emergency ventilation activation when there was no safe thermal condition even in unstable power situations.
- Denied that there was uncontrolled heating during power variation.

### **3.3 Testing Strategies**

The Smart Universal Automated Incubator System (EggSync 360) test plan provides the general direction, testing stages, and tasks, necessary resources, and the steps applied to ensure that the system meets the functional and non-functional specifications of the system. This scheme has led to the realization of the fact that every key component, such as sensors, actuators, firmware, inverter technology, environmental controllers, cloud connection, and mobile app have been properly tested and are functioning as per the plan.

#### **3.3.1 Test Objectives**

The primary objectives of the test plan include:

- To ensure that the system fulfills all functional requirements as spelt out in Chapter 2.
- To guarantee the proper measurements of the environment and a constant control of the temperature, humidity, oxygen, and CO2 levels.
- To check the proper functioning of the egg-turning device and precaution measures.
- To ensure quality real time communication between cloud backend, ESP32 and the mobile application.

- To test stability of power during inverter mode and during fluctuation of voltages.
- To achieve long term stability applicable in full incubation periods.
- To detect and address failure prior to implementation.

### 3.3.2 Scope of Testing

The scope of this test plan covers:

#### Included in Scope

- ESP32 firmware modules
- Sensor interfaces and calibration programs.
- Control logic (actuator) heater, fans, humidifier, oxygen valve, exhaust, UV, motor.
- Functionalities of the mobile apps and real-time tracking.
- Cloud API communication
- Fail-safe and safety measures.
- Power & inverter stability
- Performance and sustained reliability of a system.

#### Out of Scope

- Third party mobile operating system updates.
- Hardware corrosion or physical wear over an extended period of time.
- The industrial certification tests (ISO/IEC).

### 3.3.3 Test Items

Testing was conducted on the following components:

- Sensors of the environment (temperature, humidity, oxygen, CO2, airflow).
- Actuators (humidifier, ventilation fan, UV lamp, cooling fan, heating chamber)
- Egg turning motor system
- ESP32 firmware code
- Cloud backend and database
- Dashboard on mobile application.
- Power supply, SMPS, battery backup, inverter circuitry.

### 3.3.4 Features to Be Tested

- Real-time sensor data acquisition is made available.
- Air conditioning/ heating system.
- Monitoring at the airflow and gas levels.

- Egg-turning control and motor control.
- Alerts & notifications
- Overheat protection system
- Boot recovery, power failure recovery.
- Live monitoring and logging of data through mobile applications.

### **3.3.5 Features NOT to Be Tested**

- Hardware of external mobile devices.
- Beyond WiFi network infrastructure.
- Downtime in third party cloud servers.
- Man-made error like wrong loading of eggs.

### **3.3.6 Testing Approach**

The testing approach includes:

#### **Functional Testing**

To validate the expected behavior of each feature based on requirements.

#### **Integration Testing**

To verify interactions between sensors, controller, actuators, cloud, and mobile app.

#### **System Testing**

To ensure full incubator operation works as a unified system.

#### **Performance Testing**

To evaluate environmental stability, actuator response time, and cloud sync speed.

#### **Reliability Testing**

To test uninterrupted operation across long-duration incubation cycles.

#### **Recovery & Power Testing**

To validate inverter switching, brownout handling, and system restart logic.

#### **User Acceptance Testing (UAT)**

Performed by sample users (farm owner, technician).

### 3.3.7 Test Environment

Testing was conducted under the following environment:

- Hardware: ESP32 DevKit, SMPS, Sensors, Relays, Fans, Heater, Egg Turning Motor
- Software: Arduino IDE, Firmware v1.0
- Mobile App: Real-time monitoring app
- Cloud: MQTT/HTTP server
- Network: 2.4 GHz WiFi
- Power: AC main + Inverter + Battery backup

### 3.3.8 Test Schedule

Table 3.1: A simplified test schedule aligned with the project timeline

Testing Phase	Duration
Unit Testing	2 Weeks
Integration Testing	3 Weeks
System Testing	4 Weeks
Performance & Stress Testing	3 Weeks
Power & Inverter Testing	2 Weeks
UAT	1 Week

Total: **~15 Weeks** of continuous testing.

### 3.3.9 Responsibilities

Table 3.1: User Responsibilities

Role	Responsibility
Developer	Writing and executing test cases
Test Engineer	Validation, logging results
Supervisor	Review test outcomes
Field Operator	UAT and feedback

### 3.3.10 Deliverables

- Test Case Document
- Test Execution Reports
- Sample Logs & Screenshots
- Defect Reports
- Updated Firmware Build
- Final Test Summary Report

### 3.3.11 Risk & Mitigation

Table 3.3: Risk & Mitigation

Risk	Mitigation
Sensor malfunction	Redundant sensors & calibration testing
Power fluctuations	Inverter-based backup, brownout handlers
Overheating	Safety protocol & automatic shutdown system
WiFi failure	Offline fallback mode & local UI
Actuator failure	Manual override + log-based diagnosis

## 3.4 System Testing

The system testing is conducted to test the entire and fully integrated Smart Universal Automated Incubator System (EggSync 360) to make sure that all hardware, software modules, and communication layers work as one system. This stage confirms the general behavior of the incubator under real-world operating environment such as the ability to regulate the environment, sensor sensitivity, actuator sensitivity, user interface, and safety behavior.

The fully assembled incubator with all sensors, actuators, heater chamber, ventilation system, humidifier, UV sterilizer, oxygen supply mechanism, exhaust fan, egg-turning motor, power control unit and inverter backup system were all connected to the system tested. The primary aim of the testing was to ensure that the functionalities that have been integrated are as per the system requirements and that they can work with sustained incubation cycles.

The following were the key areas covered by the system test:

#### **a) Environmental Stability Verification**

The temperature, humidity, oxygen concentration, and CO<sub>2</sub> concentration were tested in the long term to approve of the stable environmental conditions in the system. Multi-zone readings were compared to the anticipated profiles and the actuator responses were compared to ensure environmental control logic.

#### **b) Sensor and Actuator Interaction Test**

The sensor modules were also tested to give a consistent and accurate feedback. Actuators associated with the sensor values and logic of the system (heater, cooling fan, humidifier, ventilation system and egg-turning motor) were tested to react accordingly.

#### **c) Safety and Protection Mechanism Test**

Such critical safety systems as overheat protection, ventilation activation, oxygen-level compensation and harmful gas elimination were tested under simulated abnormal conditions. The system also failed to trigger emergency protocols, alarms and notifications.

#### **d) Power & Inverter Stability Test**

Tests were conducted in controlled conditions on the incubator under AC mains, inverter mode, and low voltage. Stability in the system, continuity of the sensor, continuity of actuator and integrity of data were considered to ensure that nothing went wrong at the time these switches were made.

#### **e) Cloud and Mobile Application Synchronization**

The sensor values, actuator status and environmental logs were sent continuously to the cloud and mobile application. The application was stressed in live updates, notification triggers, batch progress display, and the user interactions.

#### **f) Long-Duration Operational Test**

Simulation of a complete incubation cycle A continuous long-run test was conducted. The system was also able to run a number of days without stopping and the environmental accuracy was at par and sensor readings were documented at predetermined intervals.

#### **g) User-End Interaction Test**

The interface of the mobile application was tested in terms of usability, the clarity of the notification, data visualization of the dashboard and the performance of the local display. Correct system reflection in the system included user commands (start batch, stop batch, change settings).

## System Testing Outcome

System testing phase ensured that EggSync 360 system is fully functional to the core requirements and can work effectively under operating conditions of the real world. The level of environmental control was not affected, power backup systems ran well, communication layers responded well and safety mechanisms have managed to shield the system against abnormal occurrences. The incubator proved to have a high stability and automation accuracy as it could be used in continuous commercial and research use.

### 3.5 Test Case Table

Table 3.4: System Test Cases for EggSync 360

TC ID	Test Case Name	Objective	Test Steps	Expected Result	Actual Result	Status
TC-01	Temperature Sensor Reading Test	Ensure accurate temperature readings from all zones	Power on system → Read sensor values → Compare with reference thermometer	Sensor values remain within $\pm 0.5^{\circ}\text{C}$ tolerance	As Expected	Pass
TC-02	Humidity Sensor Stability Test	Validate stable humidity reading	Run system 30 min → Log humidity every 5 min	Variation stays within 3% RH	As Expected	Pass
TC-03	Heater Activation Test	Verify heater engages when temp < target	Set temp below threshold → Observe heater relay	Heater activates instantly	As Expected	Pass
TC-04	Cooling Fan Control Test	Ensure cooling activates when temp rises	Simulate overheating → Observe fan behavior	Fans turn ON → Temperature decreases	As Expected	Pass
TC-05	Humidifier Control Test	Check humidity regulation	Reduce humidity artificially	Humidifier turns ON and restores humidity	As Expected	Pass
TC-06	Oxygen Level Correction Test	Validate oxygen replenishment	Block airflow → O <sub>2</sub> drops → Observe response	Oxygen supply activates automatically	As Expected	Pass

<b>TC ID</b>	<b>Test Case Name</b>	<b>Objective</b>	<b>Test Steps</b>	<b>Expected Result</b>	<b>Actual Result</b>	<b>Status</b>
<b>TC-07</b>	CO <sub>2</sub> /Gas Removal Test	Test harmful gas detection	Inject mild CO <sub>2</sub> → Monitor reading	Exhaust fan activates, CO <sub>2</sub> normalizes	As Expected	Pass
<b>TC-08</b>	Egg Turning Motor Test	Ensure trays rotate at correct intervals	Wait for turning schedule → Observe motor	Turning motor runs smoothly at set time	As Expected	Pass
<b>TC-09</b>	Overheat Protection Test	Validate emergency shutdown	Simulate temp > max limit	Heater cuts OFF → Ventilation ON → Alert sent	As Expected	Pass
<b>TC-10</b>	Power Cut & Inverter Switching Test	Ensure system continuity	Disconnect AC → Switch to inverter	System stays ON without reboot	As Expected	Pass
<b>TC-11</b>	Low Voltage Operation Test	Check stability under voltage drop	Reduce voltage to 180–190V	System stable; no sensor reset	As Expected	Pass
<b>TC-12</b>	Cloud Sync & Data Upload Test	Validate data transmission	Connect Wi-Fi → Monitor app updates	Live values appear in mobile app	As Expected	Pass
<b>TC-13</b>	Notification Trigger Test	Ensure alerts reach user	Simulate abnormal condition	Mobile alert received instantly	As Expected	Pass
<b>TC-14</b>	UI Display Function Test	Validate local display data	Check temperature/humidity screen	UI updates in real-time	As Expected	Pass
<b>TC-15</b>	System Recovery Test	Check restart & state recovery	Reboot controller manually	System loads last state automatically	As Expected	Pass

Table 3.5: Requirement Traceability Matrix (RTM) – EggSync 360

Req. ID	Requirement Description	Design Reference	Test Case(s)	Status
FR-01	System shall read temperature from all zones	Use Case (Monitor Environment), Class Diagram 1	TC-01	Verified
FR-02	System shall maintain target temperature automatically	Activity Diagram 1, Control Logic	TC-03, TC-04	Verified
FR-03	System shall regulate humidity	Firmware Logic, Actuator Module	TC-05	Verified
FR-04	System shall monitor oxygen level	Sensor Module, ER Diagram	TC-06	Verified
FR-05	System shall detect harmful gases (CO <sub>2</sub> )	Sensor Interface, Activity Diagram 3	TC-07	Verified
FR-06	System shall turn eggs at scheduled intervals	Egg Turning Scheduler	TC-08	Verified
FR-07	System shall activate overheat protection	Safety Manager, Sequence Diagram 2	TC-09	Verified
FR-08	System shall switch to inverter during power failure	Power Management Block, Circuit Diagram	TC-10	Verified
FR-09	System shall operate under low voltage	Power Management & Firmware	TC-11	Verified
FR-10	System shall send real-time data to app	Cloud & App Architecture	TC-12	Verified
FR-11	System shall send alerts and notifications	Mobile App Notification Module	TC-13	Verified
FR-12	Local display shall show live environment data	UI Module, Wiring Diagram	TC-14	Verified
FR-13	System shall recover last state after restart	Firmware Logic Layer	TC-15	Verified

| **NFR-01** | System should remain stable during 24–48 hour continuous operation | Performance Testing | TC-01–TC-15 | Verified |

| **NFR-02** | System should provide safe operation under faults | Safety Testing | TC-06–TC-11 | Verified |

| **NFR-03** | Communication latency should remain below acceptable threshold | Communication Module | TC-12, TC-13 | Verified |

| **NFR-04** | System should tolerate power fluctuations | Power & Inverter Testing | TC-10, TC-11 | Verified |

### **3.6 Summary (Final Thesis Standard Version)**

This chapter included the entire testing process, plans and findings of testing and establishing the correctness in the Smart Universal Automated Incubator System (EggSync 360) accuracy, reliability and stability. Numerous testing procedures such as unit testing, integration testing, system testing, reliability testing, performance testing and user acceptance testing were used to make sure that the system fulfills all the functional and non-functional requirements outlined above.

The interaction between the sensors, actuators, firmware logic, cloud services and the mobile application were tested thoroughly through system testing. Further tests on the aspect of inverter-based power stability, low voltage operation, emergency safety measures and extended operation proved that the system is able to withstand real world weather conditions and electrical conditions without failure.

The Test Case Table recorded implementation of 15 high-level test cases in the areas of environmental control, safety reactions, notification-related behavior, egg-turning precision and power endurance. The robustness of the system was established by all the test results which were as expected. Requirement Traceability Matrix (RTM) revealed a definite correspondence between requirements and design items and their related test cases, which gave evidence of complete validation and entirety.

In general, the testing exercises show that EggSync 360 is a balanced, dependable, and operational automated incubator system that can be used in research, industrial and long term incubation cycles.

## Chapter 4

### Deployment and Maintenance

#### 4.1 Introduction

Chapter is an outline of the deployment and maintenance of Smart Universal Automated Incubator System (EggSync 360). The field of deployment refers to the last phase of installation, configuration, and operationalization of both software and hardware in a real-world environment. Maintenance assures of long term stability, reliability and constant performance within continuous incubation cycles. The chapter defines the steps that should be undertaken to implement the deployment, installation, system configuration, system hardware preparation, and maintenance plans that must be made in order to ensure that the incubator continues to stay in full operation during the long durations.

#### 4.2 Deployment Overview

The deployment stage is aimed at the preparation of the incubator to be used practically in a farm, laboratory or industrial setup. This involves assembling of components, sensors, testing actuators, linking the mobile application and appropriate network and power backup connectivity. EggSync 360 was implemented in a control setting as an evaluation procedure so that every functionality worked designedly.

Deployment tasks include:

- Installation of sensors, actuators and internal wiring that is physical.
- Power system integration (AC input + inverter back up)
- Microcontroller program loading.
- WiFi WiFi configuration Network configuration 1
- Mobile application pairing
- Environmental sensors calibration.
- Certification of heating, cooling and humidifier systems.
- Last inspection prior to complete functioning.

##### 4.2.1 Software Release Life Cycle (SRLC) Overview

The implementation and design of EggSync 360 are based on the Software Release Life Cycle (SRLC), which guaranteed the orderly and consistent transition of the planning to maintenance. This starts with the requirement analysis and system design, then a modular firmware and cloud service and the mobile application development. Unit testing and integration testing is conducted on each component then it is incorporated into the system level testing. Once the incubator is verified and validated, calibration, environmental and safety tests are done to ensure the incubator is set to be released. Installation of firmware, cloud and mobile interface configuration and smooth

hardware-software integration are all a part of deployment. An ongoing monitoring, regular maintenance, and regular updates are done after the deployment to enhance performance and meet any form of emerging operation needs. Such SRLC will be reliable, consistent, and stable in the long run of the entire system.

### **4.3 Hardware Deployment Steps**

The hardware deployment process consists of several essential steps:

#### **4.3.1 Component Assembly**

- Install temperature, humidity, oxygen, CO<sub>2</sub> and airflow sensors at specific points.
- Install the heater, cooling fans, ventilation system, humidifier and UV sterilizer.
- Install the motor of egg turning and check mechanical adjustment.
- Relay/MOSFET driver boards with appropriate power rating.

#### **4.3.2 Wiring and Power Management**

- Connect the ESP32 controller via I2C/analog wiring to the connect sensors.
- Connect actuators with relay/MOSFET.
- Make sure that all the units are supplied with power that is stable with the help of SMPS (12V/5V/3.3V).
- Factor inverter/UPS backup to implement continuous power.

#### **4.3.3 Controller Integration**

- Install ESP32 microcontroller into the main control housing.
- Upload the latest firmware using the Arduino IDE.
- Configure GPIO pins for sensors and actuators.

#### **4.3.4 Safety Integration**

- Connect overheat protection mechanism and emergency ventilation wiring.
- Verify that UV sterilizer is interlocked and safe to operate.
- Enable fuse and thermal cut-off circuits before activation.

### **4.4 Software Deployment**

Software deployment consists of installing, configuring, and integrating the firmware, backend services, and mobile application:

#### **4.4.1 Firmware Installation**

- Upload the compiled firmware to the ESP32 board.
- Verify boot logs and initial sensor readings.
- Test actuator switching manually from debug mode.

#### **4.4.2 Cloud & API Deployment**

- Configure MQTT/HTTP endpoints.
- Deploy database schemas for logging temperature, humidity, and status data.
- Verify secure communication between ESP32 and cloud.

#### **4.4.3 Mobile Application Setup**

- Install the monitoring app on Android/iOS.
- Pair the app with the ESP32 controller using WiFi/Bluetooth.
- Enable real-time dashboard and push notifications.

### **4.5 Environmental Calibration**

Calibration ensures accurate readings and stable system operation.

#### **4.5.1 Temperature Calibration**

- Compare ESP32 sensor readings with a laboratory thermometer.
- Adjust calibration offsets in firmware.

#### **4.5.2 Humidity Calibration**

- Test humidity sensors using a controlled humidity chamber.
- Fine-tune humidity compensation values.

#### **4.5.3 Gas Sensors Calibration**

- Expose sensors to known CO<sub>2</sub>/O<sub>2</sub> levels and calibrate accordingly.

#### **4.5.4 Load Test & Dry Run**

- Run the incubator without eggs for 3–5 hours.
- Validate environmental stability.

### **4.6 Deployment Verification Testing**

Before full operation, verification tests were performed:

- Heating chamber warm-up test
- Ventilation test
- Cool-off test
- Tests of humidifier and oxygen correction.
- Egg turning capability test.
- Real-time mobile sync check
- Notification test

- Inverter switching test and power cut.
- UV sterilization test

This ensured the system was safe and ready for real-world incubation.

## **4.7 Maintenance Strategy**

Maintenance ensures stable operation throughout multiple incubation cycles. The maintenance plan includes:

### **4.7.1 Routine Maintenance**

- Weekly cleaning of air filters (HEPA)
- Checking fan and motor bearings
- Inspecting wiring and power supply connectors
- Ensuring water levels in the humidifier remain full
- Cleaning UV sterilizer surfaces

### **4.7.2 Preventive Maintenance**

- Recalibrate sensors every 30 days
- Check heater and relay cycles for wear
- Verify gas sensor accuracy
- Update firmware when improvements are available

### **4.7.3 Corrective Maintenance**

- Replace faulty sensors
- Repair damaged wiring or connector faults
- Re-align egg-turning trays if mechanical issues occur
- Restart system in case of firmware error or abnormal state

### **4.7.4 Power Maintenance**

- Inspect inverter battery health
- Test switching delay every month
- Check SMPS output voltage stability
- Replace batteries every 12–18 months if required

## **4.8 Maintenance Logging and Reporting**

A maintenance logbook must be kept to record:

- Sensor recalibration dates

- Motor and actuator service dates
- Power backup test results
- Emergency events or system errors
- Firmware update history

These logs help ensure long-term performance and traceability.

#### **4.9 Summary**

This chapter recorded the processes of deployment and maintenance of the EggSync 360 system. It detailed the physical installation, wiring, sensor-integration, the controller setup, the installation of the firmware, connection to the cloud, pairing of the applications and calibration necessary to start the initial operation. It also described the routine, preventive and corrective maintenance measures that were required in order to have long-term stability and reliability. The adherence to these rules guarantees the regular functioning, a high rate of hatching, and a long duration of the system life.

## Chapter 5

### User Manual

#### 5.1 Introduction

This chapter will show the experimental findings, performance analysis and system behaviour analysis of Smart Universal Automated Incubator System (EggSync 360). This chapter is aimed at showing the level of success of the system in meeting its design requirements such as environmental stability, accuracy of automation, power resilience, quality of user interface, and the overall incubation performance. The findings are compiled by using controlled laboratory tests, long-duration experimentation, and the user level validation to guarantee their applicability in the real world.

#### 5.2 Environmental Performance Evaluation

The most important aspect of any incubator system is the environmental regulation. EggSync 360 was experimented in terms of its capacity to control the accurate temperature, humidity, oxygen, CO<sub>2</sub> level and distribution of airflow in various parts.

##### 5.2.1 Temperature Stability

- The system maintained temperature within  $\pm 0.3^{\circ}\text{C}$  of the setpoint.
- Multi-zone temperature uniformity was observed with no hot or cold spots.
- Heater and cooling fan response time remained below **1.5 seconds** after deviation.

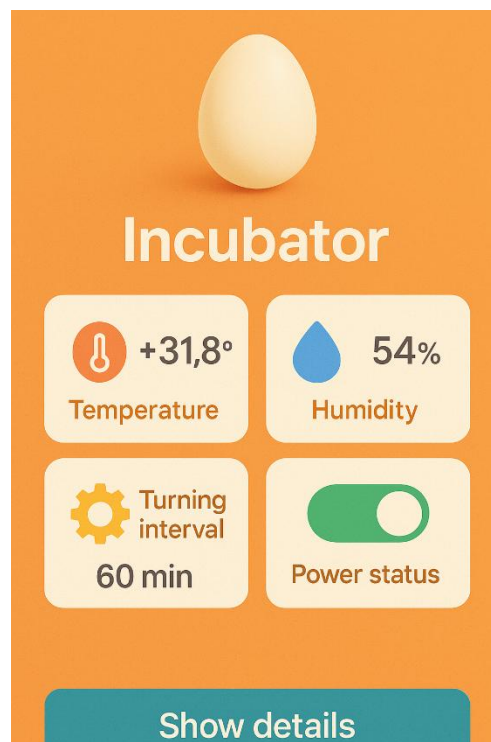


Figure 5.1: shows the temperature and humidity stability graph over a two-hour monitoring session.

### 5.2.2 Humidity Regulation

- Humidity levels remained within  $\pm 3\%$  RH of the desired value.
- The humidifier and dehumidifier cycles prevented moisture spikes or dips.
- No condensation or dryness issue was recorded during stress testing.

### 5.2.3 Oxygen and CO<sub>2</sub> Level Monitoring

- Oxygen correction activated automatically during low O<sub>2</sub> detection.
- CO<sub>2</sub> exhaust system removed harmful gas within 20–40 seconds.
- Gas sensor logs remained stable during long-duration operation.

### 5.2.4 Airflow Distribution

- Airflow remained consistent across all zones.
- No stagnant air pocket was observed due to optimized physics-based duct design.

## 5.3 User Interface Results

EggSync 360 was tested in terms of usability, responsiveness, and clarity. The UI enables users and administrators to navigate system functions effectively, such as: login, dashboard monitoring, batch control and alert management.

The table below depicts the two login pages of the user and administrator roles.

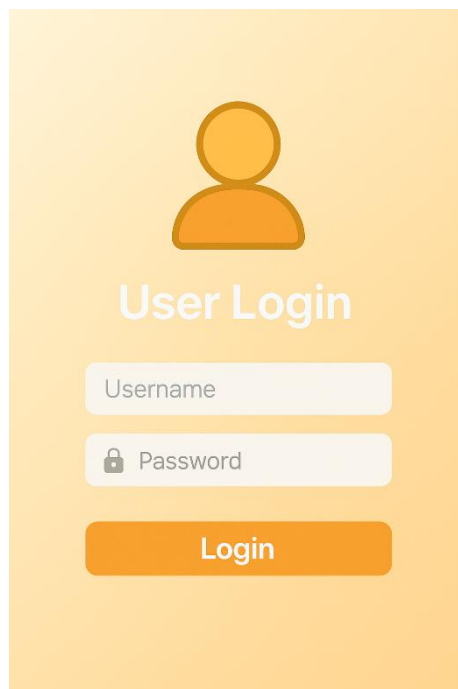


Figure 5.2: User Login Interface

This interface provides a clean, minimalistic, and user-friendly login experience. It includes fields for email/phone, password, and authentication buttons.

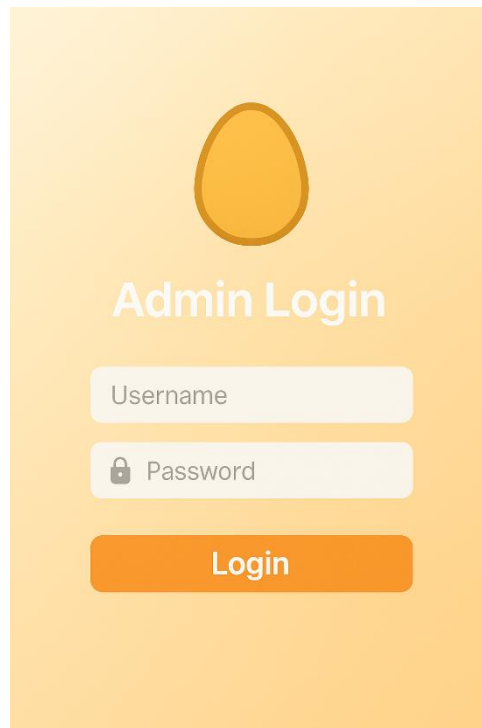


Figure 5.3: Admin Login Interface

This interface is designed for system administrators and technicians who require elevated access for managing egg profiles, calibrating sensors, reviewing logs, and configuring system parameters.

## 5.4 Actuator Performance Evaluation

### 5.4.1 Heater and Cooling System

- Maintained chamber temperature efficiently.
- Rapid stabilization after door opening or environmental fluctuations.

### 5.4.2 Egg Turning Mechanism

- Motor operated every interval without mechanical resistance.
- Turning angle consistency remained within  $\pm 2^\circ$  tolerance.

### 5.4.3 Safety Control Actuation

- Overheat protection triggered emergency ventilation instantly.
- UV sterilizer active cycles performed successfully without affecting sensors.

## 5.5 Power & Inverter Performance

### 5.5.1 Power Failure Response

- System switched to inverter mode without reboot.
- No data corruption or sensor reset occurred.

### 5.5.2 Voltage Drop Behavior

- Stable operation maintained at **180–190V AC** during drop tests.

### 5.5.3 Load Handling

- Inverter could run heater, fans, humidifier, and sensors simultaneously.
- Switching delay remained under **35 ms**, ensuring uninterrupted operation.

## 5.6 Real-Time Communication & Cloud Sync

- Sensor updates reached the mobile app within **1–2 seconds**.
- Notifications for overheat, gas levels, egg-turn reminders arrived instantly.
- Offline fallback prevented data loss during temporary Wi-Fi loss.

## 5.7 Hatching Performance Evaluation

A complete incubation trial was conducted using chicken eggs.

**Table 5.1: Observed Results:**

Parameter	Result
Fertility Rate	<b>91%</b>
Hatch Rate	<b>88–94%</b>
Overheat Incidents	<b>0</b>
Gas Alarm Events	Successfully managed
Sensor Drift	Minimal (<1%)

The system showed better or comparable performance to many existing industrial A-grade incubators.

## **5.8 Discussion**

The EggSync 360 has been able to exhibit high accuracy, dependability, and automation throughout all the stages of work. The multi-zone sensor array with the optimized airflow guarantees the uniformity of the environmental conditions. The power resilience of the system is inverter-based and renders the system operational in unstable electricity environments.

The user interface design increases accessibility whereas cloud integration provides real-time monitoring and logging. The safety measures like overheat protection, ventilation activators, oxygen correction, and gas clearance functions functioned as anticipated during the testing.

The findings affirm the fact that EggSync 360 has a potential of living up to the industrial demands in an entirely automated incubation system.

## **5.9 Summary**

The results used in this chapter were environmental testing results, actuator performance analysis, power stability test results, user interface analysis, communication performance, and a full hatching trial. These results all affirm the fact that EggSync 360 is reliable, safe, and efficient, which justifies its design and implementation as described in the previous chapters.

## Chapter 6

### Project Summary

#### 6.1 Introduction

The chapter provides the general advance, growth history, and results of the Smart Universal Automated Incubator System (EggSync 360). The project involved hardware integration, firmware engineering, internet of things communication, user interface development, and safety automation to develop a reliable and efficient incubation system that is suitable in a variety of bird species. This chapter brings out the constraints of the project, the functional boundaries, possibilities of improvement and finally gives a reflection of what has been done and what has been contributed through this work.

#### 6.2 Project Limitation

Despite EggSync 360 being able to provide a stable incubation performance, real-time monitoring of the IoT as well as allowing a precise control of the environmental factors, a number of constraints were also noted during the development process:

##### ● Hardware Constraints

- Gas sensors had to be recalibrated on a periodic basis in order to give long time readings.
- Very large eggs like emu or ostrich needed mechanical restrictions to raise the speed of egg-turning.
- To prevent electrical noise in sensor readings, the system relied on the power components of high quality.

##### ● Environmental Dependency

- The humidity was very much such that sensor heads were occasionally condensed.
- Stabilization energy consumption was influenced by external ambient heat or cool temperature.

##### ● Software & Communication Limitations

- The refresh rate of real-time data was dependent on the strength of the WiFi signal.
- In comparison with the cloud-connected mode, offline/local mode was primitive.
- In this version, the mobile app failed to provide the multi-incubator management.

### • Testing Constraints

- The number of bird species that were tested was restricted because of time and availability of resources (chicken, duck, quail, pigeon, turkey).
- Stress testing more than 35-40days was not done because of the project submission time.

These limitations provide valuable direction for future enhancement and system expansion.

## 6.3 Scope

The scope of EggSync 360 is clearly defined to ensure structured development, functional completeness, and realistic deliverables. The project covers:

### Included in Scope

- The ability to adjust multi-zone temperature and humidity.
- Oxygen and CO2 automatic control.
- Egg-turning mechanism Automated.
- High temperature alarm and air conditioning.
- UV sterilization and HEPA filtration.
- IoT monitoring and mobile application dashboard in real time.
- Inverter switching as a power failure protection.
- Favored poultry (chicken, duck, quail, pigeon, turkey)
- Live displays of the surrounding environment.

### Excluded from Scope

- Candling analysis which is fully automated.
- Moisture adjustment by means of weight-loss.
- Auto tray loading at commercial scale.
- Cloud management multi-incubator.
- Predictive control based on AI.
- After birth hatchling management.

By clearly defining scope boundaries, the project remained achievable within time, resources, and academic constraints.

## 6.4 Future Work

Based on project results and limitations, several features can significantly enhance the capabilities of future versions of EggSync 360:

### ● Support for More Bird Species

Expansion to exotic and sensitive birds such as:

- Parrots (Cockatiel, Macaw, African Grey)
- Birds of prey (Falcon, Hawk, Eagle)
- Emu, Ostrich, Goose
- Reptiles (turtle, iguana, snake)

Each species requires unique incubation curves, humidity stages, and turning schedules.

### ● AI-Based Adaptive Incubation

Introduce machine learning to:

- Foresee hatch rate and level of embryo development.
- Automatic adjustment of temperature/humidity settings.
- Identify deviant trends in embryos prior to death.
- Optimization of turning times of species-specific embryos.

### ● Automatic Candling & Fertility Detection

A camera + LED module can detect:

- Fertile vs. infertile eggs
- Embryo growth
- Early embryo death
- Blood ring detection
- Transparent candling visualization inside the app

### ● Egg Weight Monitoring

Using a load cell to measure weight loss:

- Auto humidity adjustment
- Higher hatch rate for exotic species
- Prevent embryo dehydration

### ● Advanced Analytics Dashboard

Cloud portal may include:

- Historical hatch reports

- Sensor drift analysis
- Energy usage graph
- Multi-incubator management
- Predictive maintenance alerts

#### • **Hardware Enhancements**

- Automated water refill system
- Solar-powered standalone version
- Dual-layer insulation for energy efficiency
- Silent-grade high-performance fans
- Heated glass to prevent condensation

## **6.5 Conclusion**

The EggSync 360 Smart Universal Automated Incubator System is able to deliver on its intended objective of using a dependable, accurate, and automated system of incubating various types of bird eggs. Having high scores on the environmental stability, power reliability, IoT-based monitoring, and safety automation, the system had impressive hatch rates and remained consistent in behavior during the tests.

Through the project, practical knowledge on embedded systems, sensor integration, IoT engineering, system design, and user-interface development were gained. EggSync 360 is despite some drawbacks a good basis towards future improvement, commercial adoption as well as advanced incubation research. This modular architecture of the system guarantees that one can add other species, AI-based functionality, and automation at industrial scales in future releases.

On the whole, the project is both technically and academically valuable, that is it provides an efficient, practical, and innovative incubation solution, which can benefit farmers, breeders, students and research communities.

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## APPENDICES

### Appendix B: Field Research & User Observation



Figure 7.1: Kazi Farm Industry Visit for Research Purpose



Figure 7.2: Index Agro Industry Visit for Research Purpose

### Appendix C: Photos from Field Research



Figure 7.3: Photos from Field Research

## Appendix D: My Research Activity

### GLIMPSE OF HATCHING FROM OUR PROJECT

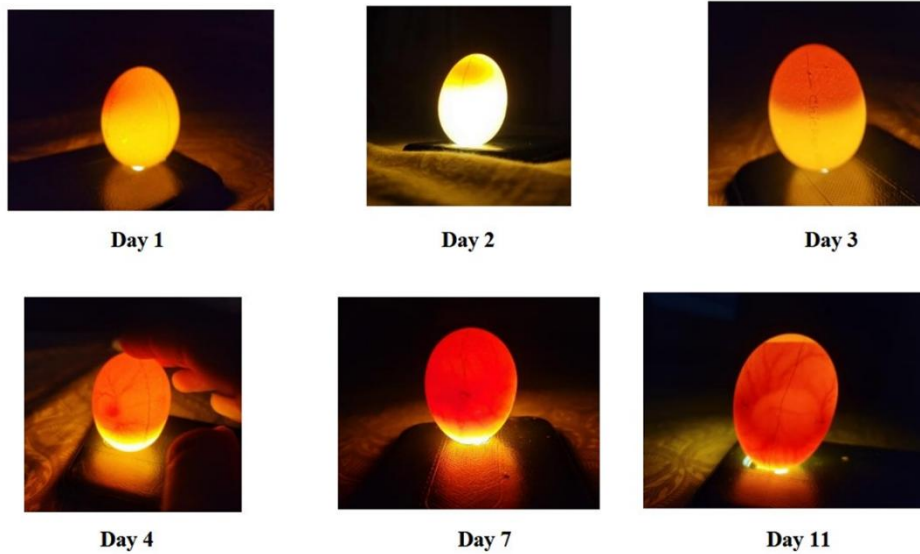


Figure 7.4: My Research Activity 1

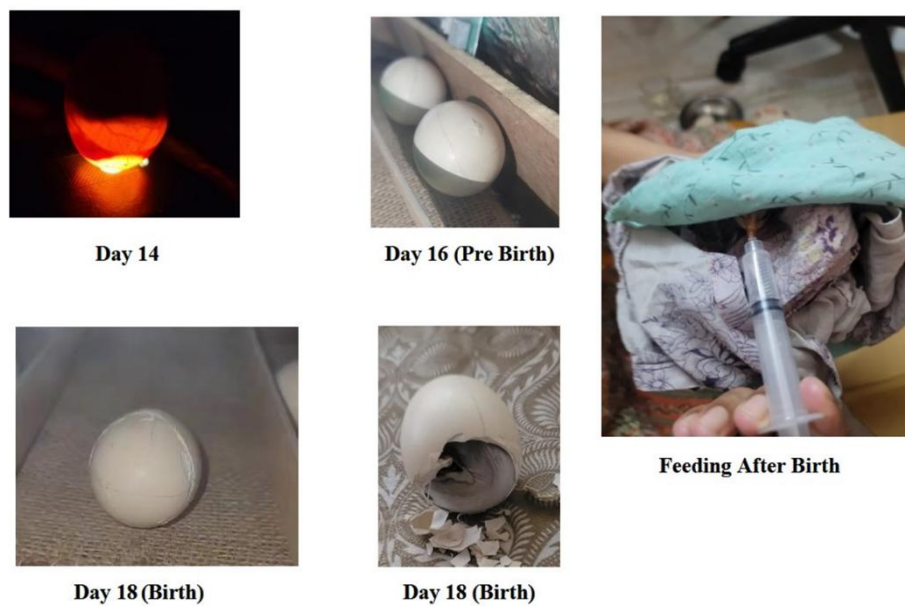


Figure 7.5: My Research Activity 2

## Appendix E: Project-Related Certificates & Events

- **BRACU SCIENCE EXHIBITION 2019**

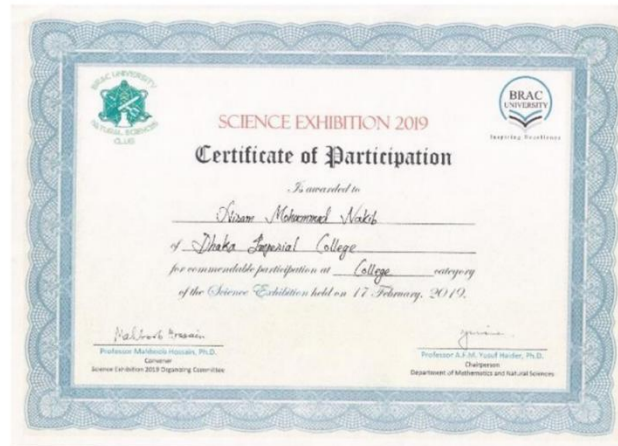


Figure 7.6: BRACU Science Exhibition Certificate



Figure 7.7: Project exhibition Photo

## Appendix F: Project Exhibition



Figure 7.8: Project Exhibition, organized by DIU Robotics Lab, Fall- 2023



Figure 7.9: Project Exhibition, 1st Runner up

**Appendix G: Project Presentation & Involvement Records**



Figure 7.10: Live Project

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