

Design and Implementation of an IoT-Based Automatic Salted Fish Dryer System Using Load Cell as an Objective Moisture Indicator

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Abstract

Fish is a highly nutritious but rapidly perishable food commodity. Traditional salted fish drying methods heavily depend on unpredictable weather conditions, often taking days to complete and leaving the product prone to contamination. While automated dryers have been introduced, most lack an objective metric to halt the process, relying instead on subjective visual inspection. This study aims to design and implement an Internet of Things (IoT)-based automatic salted fish dryer system equipped with a load cell to objectively determine the dryness level. The proposed system utilizes an ESP32 microcontroller, a DHT22 sensor, a PTC heater, and a DC fan to automatically maintain the drying chamber at an optimal temperature of 70°C. Furthermore, a load cell sensor continuously monitors weight reduction, serving as a real-time proxy for the moisture content. Operational data is transmitted via Wi-Fi to the ThingsBoard platform for remote visualization. System validation showed that the DHT22 and load cell sensors have an accuracy of over 99.20%. Experimental results on 1 kg of Sepat and Layang fish demonstrate that the automated system significantly accelerates the drying process, reducing the required time from 2-3 days to just 8 hours. The system successfully executed an automatic cut-off when the fish weight dropped by 50%, ensuring hygienic, efficient, and consistent production for small-to-medium enterprises.

Keywords: Automatic Dryer; ESP32; Internet of Things; Load Cell; Salted Fish

1. Introduction

Fish species possess significant nutritional profiles characterized by high concentrations of long-chain unsaturated fatty acids and complex proteins; unfortunately, this rich biological composition renders them highly susceptible to rapid microbial degradation [1]. Spoilage mechanisms routinely initiate within a mere eight-hour window following the post-harvest extraction from aquatic environments. To counteract this rapid deterioration, coastal communities and small-scale maritime industries rely predominantly on extensive salting and desiccation protocols [2]. Statistical assessments indicate that approximately sixty-five percent of national fishery commodities are processed through salt-curing preservation methods [3]. Despite the critical economic reliance on this processing chain, the prevailing methodologies remain fundamentally archaic. Open-air sun drying techniques are intrinsically chained to the unpredictable fluctuations of diurnal meteorological patterns. Furthermore, exposing the biological harvest to uncontrolled atmospheric conditions significantly increases the probabilities of hazardous contamination by airborne particulate matter, dust accumulation, and insect-borne pathogenic vectors, which collectively degrade the hygienic standards of the final consumable product [4].

Recent technological paradigms surrounding the Internet of Things (IoT) have catalyzed the development of numerous automated intervention strategies aimed at neutralizing these environmental vulnerabilities [5]. A multitude of prior academic investigations has endeavored to optimize the thermal mechanics of fish drying ovens. For instance, studies deploying automated mechanisms governed by fuzzy logic algorithms have successfully demonstrated enhanced thermal stability within drying chambers [6]. Similarly, the integration of web-based microcontrollers linked to environmental sensors has proven capable of substantially compressing the drying timeline, reducing a process that manually consumes up to twenty-seven hours down to a streamlined eight-hour operational cycle [7]. However, a critical analytical review of the existing literature uncovers a systemic methodological deficiency: the pervasive reliance on either rigid temporal timers or subjective visual estimations to designate the conclusion of the active drying sequence [8]. These conventional triggers completely disregard the dynamic variables of the initial specimen mass, inherent cellular water retention rates, and shifting atmospheric pressures. Consequently, such systems exhibit a high propensity to either over-dry the biological tissue wasting electrical energy and denaturing structural proteins or prematurely halt operations, leaving residual capillary moisture that ultimately fuels latent microbial proliferation [9].

In response to these pervasive operational limitations, this research introduces an innovative automated architecture that forces a paradigm shift from arbitrary time-based evaluations to an objective, mass-reduction metric. By physically integrating a calibrated high-capacity load cell within the drying matrix, the system continuously tracks the real-time weight depreciation of the fish [10]. This structural weight loss serves as a highly accurate, non-invasive proxy for internal moisture content evaporation. Consequently, the primary objective of this study is to meticulously design, construct, and empirically validate an IoT-enabled drying cabinet capable of autonomously manipulating internal thermodynamics to a target of 70 to 75 degrees Celsius, while subsequently commanding a complete system shutdown the exact moment the biological mass registers a predetermined structural reduction threshold.

2. Research method

This study employs a prototyping methodology encompassing system design, hardware assembly, software implementation, and real-world testing. The prototype is constructed using an aluminum cabinet with dimensions of 60 cm (height) x 50 cm (width) x 60 cm (length) to accommodate a maximum capacity of 1 kg of fish. Aluminum was chosen for its lightweight properties, adequate thermal conductivity, and resistance to corrosion in high-humidity environments.

2.1. Hardware Design and System Architecture

The core of the system architecture relies on an ESP32 microcontroller, selected for its built-in Wi-Fi capabilities and power efficiency [11]. For data acquisition, a DHT22 sensor is utilized to monitor the temperature and humidity [12], while a 5 kg load cell, coupled with an HX711 amplifier, measures the weight of the fish [10]. The ESP32 processes these sensor inputs and subsequently controls a 2-channel relay module. This relay acts as an electronic switch to operate the output actuators: a 300-watt PTC heater and a DC exhaust fan. Furthermore, an I2C LCD provides localized data visualization, while the ThingsBoard cloud platform acts as the IoT dashboard for remote monitoring [13]. The logical data flow and interconnection between these components are systematically illustrated in the block diagram (Fig. 1).

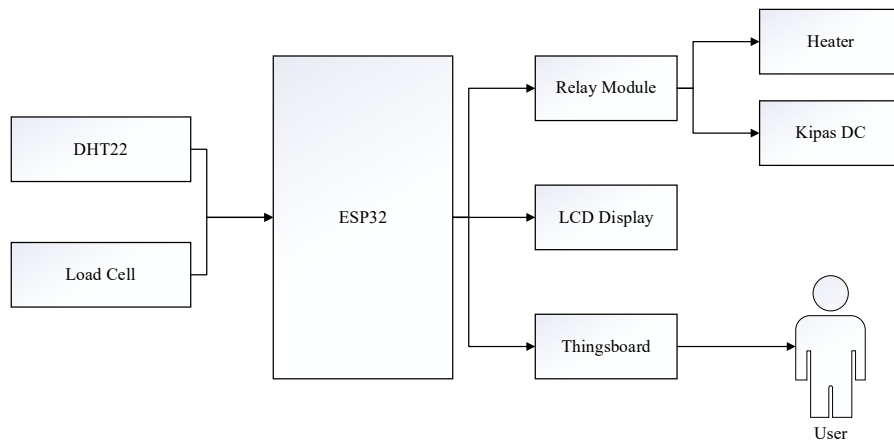


Fig. 1: Block Diagram

Beyond the logical connections, the physical placement of these components is highly critical for operational durability. To ensure optimal thermal distribution and to protect the sensitive electronic units from the harsh drying environment, the physical layout adopts a dual-compartment design, as depicted in the 3D system model (Fig. 2).

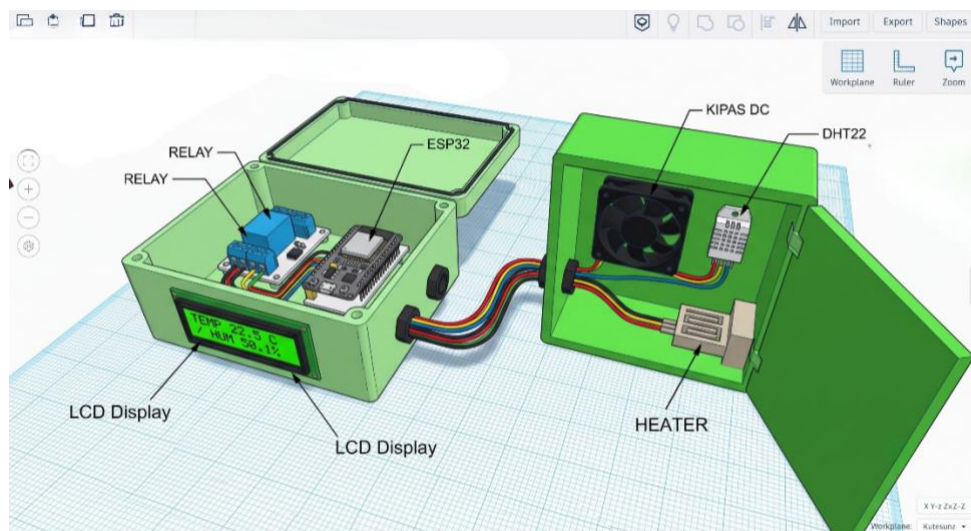


Fig. 2: 3D System Design

As observed in the design, the control electronics including the ESP32, relays, and LCD are safely isolated in a separate external housing. Meanwhile, inside the main drying chamber, the 300-watt PTC heater is installed at the bottom to allow upward heat convection, ensuring uniform temperature distribution across the biological mass. The DC exhaust fan is positioned on the upper side wall to efficiently extract excessive moisture. Finally, the load cell is securely placed directly beneath the drying rack to provide accurate, real-time weight measurements of the fish without interfering with the internal airflow [14].

2.2. Control Logic and Firmware

The firmware was developed using the Arduino IDE. The operational sequence and autonomous decision-making process of the system are mapped out in the control logic flowchart (**Fig. 3**). The primary control logic operates on a continuous feedback loop, utilizing a threshold-based rule designed to maintain a consistent high-temperature environment. The DHT22 sensor data triggers the relay and actuators as follows:

1. If the measured temperature is $< 70^{\circ}\text{C}$ or humidity is $> 40\%$ RH, the ESP32 triggers the relay to activate the PTC Heater.
2. If the temperature exceeds 75°C or humidity drops below 30% RH, the PTC Heater is deactivated, and the DC fan is turned on to circulate the air and extract excessive moisture.
3. The load cell continuously monitors the weight percentage drop. If the weight drops by $\geq 50\%$ from the initial weight, the system considers the optimal moisture content achieved and automatically shuts off all actuators.

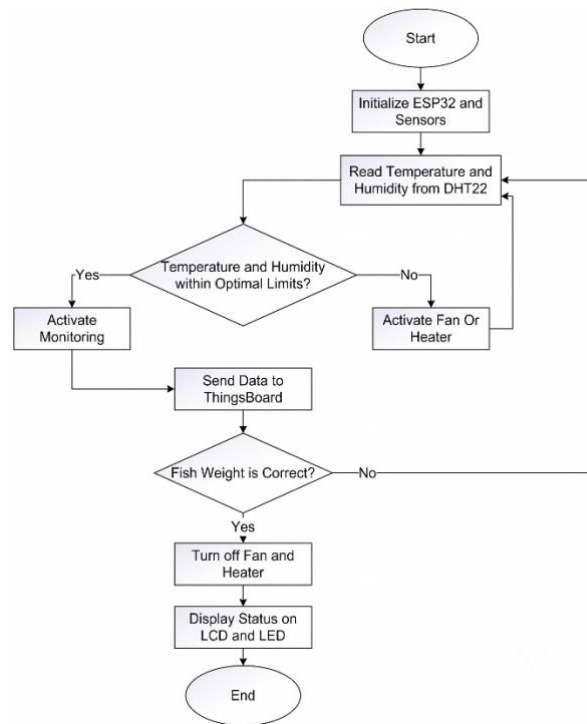


Fig. 3: Control Logic Flowchart

As illustrated in the flowchart, as long as the fish weight reduction target has not been met, the microcontroller will continuously loop back to read the DHT22 sensor, dynamically adjusting the heater and fan based on real-time conditions [15]. Concurrently, the operational status and sensor data are transmitted to the ThingsBoard platform every 60 seconds via Wi-Fi. The dashboard is configured to display historical charts, real-time gauges, and telemetry tables to ensure the user can actively monitor the ongoing process remotely.

2.3. Evaluation Metrics

The autonomous behavior of the system was algorithmically encoded through the Arduino Integrated Development Environment (IDE). The technical evaluation involves black-box testing focusing on sensor accuracy, control latency, and network stability. Sensor accuracy is calculated using the Absolute Error percentage formula:

$$Error(\%) = \left| \frac{M - R}{R} \right| \times 100\% \quad (1)$$

Where M is the measured value by the prototype and R is the reference value from calibrated standard instruments. The fish weight reduction during the drying process is calculated as:

$$Weight\ Reduction(\%) = \frac{W_{initial} - W_{current}}{W_{initial}} \times 100\% \quad (2)$$

3. Results and Discussion

The prototype was subjected to rigorous technical testing and real-world application trials in Samarinda, Indonesia, utilizing two common salted species: Sepat and Layang fish.

3.1. Sensor Accuracy and IoT Network Reliability

The reliability of the automatic control relies heavily on the accuracy of the sensors. The DHT22 sensor readings were compared against a calibrated digital reference thermometer and hygrometer, while the load cell was calibrated using standardized weights.

Table 1: Accuracy Validation of System Sensors

Sensor Type	Test Parameter	Reference Value	Measured Value	Absolute Error (%)
DHT22	Temperature	70.0 °C	70.5 °C	0.71%
DHT22	Humidity	60.0 % RH	63.0 % RH	5.00%
Load Cell	Weight	500.0 Gram	498.5 Gram	0.30%
Load Cell	Weight	1000.0 Gram	997.0 Gram	0.30%

As shown in Table 1, the sensors exhibit excellent precision. The maximum temperature deviation was 0.5°C, perfectly aligning with the DHT22 factory specifications. The load cell maintains an accuracy of over 99.70%, which is critical for determining the end-point of the drying process without false triggers.

Furthermore, the system's responsiveness to environmental changes was tested to validate its "real-time" claim.

Table 2: Control Latency of Automated Actuators

Initial Condition	Trigger Event	System Action	Response Time (ms)
Temp 68°C	Temp drops to 67.5°C	Relay activates PTC Heater	150 ms
Temp 74°C	Temp rises to 75.5°C	Relay deactivates Heater, activates Fan	180 ms
Humidity 45%	Humidity rises to 50%	Relay activates Fan	210 ms

Table 2 demonstrates that the ESP32 logic processes sensor data and sends control signals to the relay with extremely low latency (150-210 ms). This prevents temperature overshoot that could damage the fish's protein structure and ensures excessive water vapor is immediately extracted by the fan.

To evaluate the remote monitoring capabilities, a continuous 6-hour network stress test was conducted on the ThingsBoard integration.

Table 3: IoT Network Stability and QoS (6-Hour Operation)

Test Parameter	Value
Total Duration	360 minutes
Expected Data Points	360 transmissions (1 per minute)
Successful Transmissions	358 data points
Packet Loss	0.55% (2 missing packets)
Average Latency to Cloud	350 ms

The exceptionally low packet loss of 0.55% confirms that the Wi-Fi module on the ESP32 maintains a stable connection with the cloud server, providing fishermen or enterprise owners with reliable remote monitoring without major data interruptions.

3.2. Fish Drying Process Analysis

The performance of the automated dryer was evaluated by drying 1 kg of salted Sepat fish and 1 kg of salted Layang fish. According to Indonesian National Standards (SNI 2721.01.2009) for salted fish, the ideal moisture content for a long shelf life is $\leq 35\%$. In this system, a 50% reduction from the initial wet weight is empirically set as the threshold for optimal dryness.

Table 4: Drying Process Results for 1 Kg of Sepat Fish at 70°C

Time (Hours)	Average Temp (°C)	Average Humidity (% RH)	Fish Weight (Grams)	Weight Reduction (%)
0	30.0	85.0	1000	0%
2	70.8	65.0	850	15%
4	71.2	52.0	720	28%
6	70.5	40.0	600	40%
8	71.0	38.0	480	52%

Table 4 demonstrates the system's ability to rapidly stabilize the internal temperature. Within 8 hours, the Sepat fish weight dropped from 1000 grams to 480 grams (a 52% reduction). At this specific metric, the load cell logic triggered the system to automatically stop the heating process, correctly determining that the fish had reached the targeted dry state without human intervention.

Table 5: Drying Process Results for 1 Kg of Layang Fish at 70°C

Time (Hours)	Average Temp (°C)	Average Humidity (% RH)	Fish Weight (Grams)	Weight Reduction (%)
0	30.0	85.0	1000	0%
3	70.9	60.0	750	25%
6	71.5	45.0	550	45%
8	72.0	35.0	460	54%

Although both fish species successfully achieved the >50% weight reduction threshold within the 8-hour timeframe, a marginal difference of 2% was observed between Layang fish (54%) and Sepat fish (52%). This variation can be scientifically attributed to the distinct morphological characteristics and initial cellular compositions of the two species. Sepat fish is characterized by its thicker, denser scales, which act as a natural barrier that slightly increases resistance to moisture diffusion from the internal tissue to the surrounding air, particularly during the falling-rate period. Conversely, Layang fish a marine pelagic species typically exhibits a softer muscle texture, thinner skin, and a slightly higher initial free-water content. These biological traits allow the internal moisture in Layang fish to evaporate more readily when subjected to a constant 70°C thermal environment. Regardless of this minor morphological variance, the system proved highly capable of adapting to different species by relying on the load cell's objective mass-reduction metric rather than a fixed timer.

4. Conclusion

An IoT-based automatic salted fish dryer system has been successfully designed and implemented. By integrating a DHT22 sensor, a 300W PTC heater, and an ESP32 microcontroller, the system effectively maintains an optimal drying environment at 70°C. The novel integration of a load cell sensor proved highly accurate (>99.70%) in acting as a real-time, objective moisture content indicator. The system executed an automated operational cut-off with a rapid latency response (<210 ms) once a 50% weight reduction threshold was achieved. Experimental results show that 1 kg of fish can be perfectly dried in just 8 hours a drastic improvement over the traditional 3-day sun-drying method. The system guarantees high hygiene, zero weather dependency, and reliable remote monitoring via ThingsBoard with only 0.55% packet loss. Future developments should consider integrating renewable solar energy panels to power the heater, thereby reducing operational electricity costs for small-scale coastal industries.

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