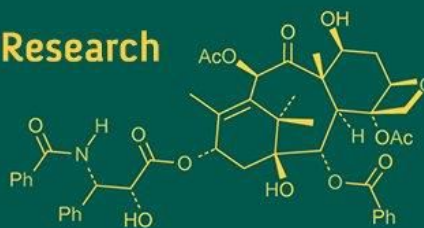


International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2025): 5.29
IJABR 2025; SP-9(8): 848-853
www.biochemjournal.com
Received: 07-05-2025
Accepted: 10-06-2025

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Development of cost effective IoT based solar cabinet dryer

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DOI: <https://www.doi.org/10.33545/26174693.2025.v9.i8Sm.5263>

Abstract

This study was inspired by the idea of increasing the efficiency of solar drying and also the quality and productivity of solar-dried products. In this study, a low-cost solar cabinet dryer was fabricated by using the design of an existing solar cabinet dryer. The cost of fabrication was lowered by using locally available and economically viable materials. Then, an IoT-based system was developed using an ESP32-based controller board, to constantly monitor the temperature, humidity, and mass of the food product. The DHT11 sensor was used for measurement of the temperature and humidity and the mass of the food product was measured by a load cell. "Blynk", a cloud-based IoT platform was used to develop remote monitoring system that enables constant monitoring of the temperature, humidity, and mass of products in the solar dryer. Then, a controlled forced circulation system, wherein the axial fan of the solar cabinet dryer is turned OFF or ON based on the humidity in the dryer, was developed by using a relay module. It turns the blower ON or OFF when the humidity in the dryer exceeds or regresses a predefined value of humidity, respectively.

Keywords: Solar cabinet dryer, IoT, Arduino, ESP32, DHT11, Blynk, mobile application, drying, low cost, energy efficient

1. Introduction

Solar drying has transformed sustainable agricultural practices by providing an environmentally friendly, low-cost, and efficient method for preserving food products. Solar dryers use solar energy to reduce moisture content in agricultural produce, thereby enhancing shelf life, quality, and safety while reducing the risks of contamination and dependency on weather associated with traditional sun drying. Among the various solar drying technologies, cabinet solar dryers have been presented as a straightforward, effective technology that can easily be scaled down for small-scale and rural applications. However, conventional solar dryers suffer from high initial costs and cannot monitor and control critical drying parameters like temperature, humidity, and airflow, which cause unevenness in product quality.

This research aims to develop an affordable IoT-based solar cabinet dryer that integrates an advanced monitoring and control system by using an ESP32-based microcontroller, allowing for real-time measurements and recording of temperature, humidity, and product mass. The IoT system is integrated with remote monitoring via the Blynk cloud platform, allowing for precise control of the drying conditions by the users and minimizing manual intervention. The second advantage is that the dryer is locally constructed using materials like MS steel and aluminum to make it strong and inexpensive.

Solar drying systems have undergone extensive research and development to overcome limitations associated with traditional drying methods (Yusuf Abdullahi, 2013) [15] emphasized the usability and portability of collapsible natural convection dryers, while also highlighting their feasibility in tropical regions with high solar irradiance (Adelaja & Babatope, 2013) [11].

The limitations of natural convection systems were overcome by incorporating biomass backup for consistent performance [Bena & Fuller, 2002]) [5]. This design was extended with solar PV-powered fans, which resulted in a considerable improvement in drying rate and energy efficiency (Goud *et al.*, 2019) [8].

Integrations of IoT technology have taken new dimensions in solar drying systems. An IoT-based monitoring system utilizing fuzzy logic for fish drying, designed to autonomously regulate temperature and humidity control (Alvinika *et al.*, 2021) [2]. Mishra *et al.*, 2023 [11] studied food quality assurance on real-time monitoring of parameters during drying using Internet of things (IoT). The Blynk App was employed for remote monitoring and control, enhancing drying efficiency while reducing the need for manual intervention (Miano *et al.*, 2023) [10]. Drying efficiency depends on several factors including temperature, humidity, airflow, and product properties. The drying kinetics significantly depend on the air velocity and temperature, whereas, the step-down strategy for the control of humidity improves the energy efficiency and quality of the products (Ertekin & Yadiz, 2004) [7]. The controlled heat and humidity played a major role for uniform drying and quality retention (Ayensu, 1997) [4]. Material selection also plays a key role in the design of low-cost and durable solar dryers. The use of low-cost materials such as mild steel and aluminum aligns with the findings of Murali *et al.* (2022) [12], who highlighted that utilizing locally available materials can help reduce costs without compromising performance (Murali *et al.*, 2022 and Rajshwari & Ramalingam, 2012) [12, 14].

Applications of solar drying technologies include various agricultural products and regions. A flexible solar tunnel dryer for the humid tropics was designed by Amir *et al.* (1991) [3]. and economic analysis of mixed-mode solar greenhouse dryers for drying red peppers and grapes were

carried out by ELkhadraoui *et al.* (2015) [6]. The progress made in solar drying technologies is broad-based and thus provides a well-rounded platform for the design of the IoT-based solar cabinet dryer presented in this work.

This project, combining efficient design, IoT integration, and cost-effective materials, demonstrates an effective solution for improving the efficiency of drying, lowering costs, and supporting sustainable agricultural practices. The monitoring system, based on IoT technology, ensures optimal drying conditions, better quality of products, and a user-friendly interface for real-time data access—a big step forward in the evolution of solar drying technologies.

2. Materials and Methods

2.1 Fabrication of solar cabinet dryer

1"x1" MS bars of 2.5mm thickness were used in the construction of the frame of the solar dryer. It was cut into required sizes based on the design below shown in Fig. 1. Then holes for bolts are drilled into these pieces, then the pieces are welded into the shape of the frame. The base of the frame is 60 x 60 cm and has a height of 56 cm at the front and 62cm at the back to form a sloping top. The frame was covered on all sides except the top with a 1 mm GI sheet, attached to the frame using nuts and bolts. The front wall is divided in half, horizontally, with the upper half used as a hatch using hinges and a handle. A 5mm Acrylic sheet was used as the top covering for the solar cabinet dryer. It was attached to the frame using GI sheet strips and was glued to these strips using silicone glue.

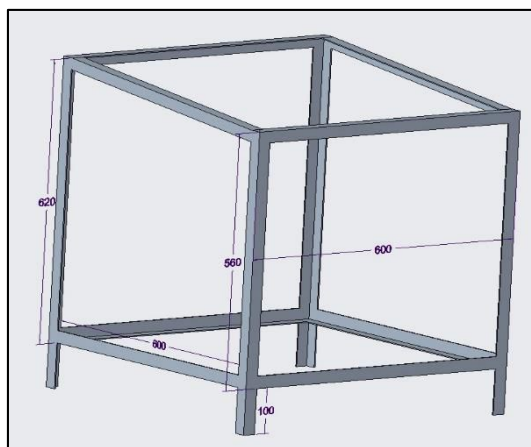


Fig. 1. Frame design

1"x1" Aluminium bar of thickness 3mm was used for tray supports. It was cut based on the design and attached to the frame using nuts and bolts. Tray supports in the solar cabinet dryer hold the trays. A 1mm aluminum sheet was used for making trays. The dimension of each tray is 54cm x 58cm. A smaller tray of 10cm x 10cm was also made for placing the representative sample on the load cell.

12 V 120 mm x 120 mm x 20mm DC Axial fan was used in the cabinet solar dryer. The operating voltage of the fan is 12V DC. This small fan can spin at speeds ranging from 6800 to 13000 rpm. The fan was installed on the back wall of the solar dryer below the solar panel. The solar panel was used only to run the axial fans. The solar panel with a voltage rating of 21 volts and a current rating of 0.57 amps, was used in this project.

The existing solar dryer was painted black on the outside but white on the inside. However, the developed solar dryer was

painted black both on the inside and the outside walls. Rubber strips cut from the tire tube were placed at the edges of the GI sheet walls in between the frame and the GI sheet to avoid air from leaking from the developed solar cabinet dryer. Thin horizontal cuts are made on the side walls near the base to allow air to enter into the solar cabinet dryer.

The existing solar dryer has two rows for placing trays and each row is divided into two parts so each row has two trays. The trays in the existing are made of stainless steel. The developed solar dryer has two rows for trays, but unlike the existing solar dryer only one large tray was placed in each row.

Fig. 2 and 3 show the front and back views of the developed solar cabinet dryer and the existing solar cabinet dryer respectively.



Fig. 2. Front and back view of developed solar cabinet dryer



Fig. 3. Existing solar cabinet dryer

2.2. Development of IoT-based monitoring and control system

The IOT-based monitoring and control system was developed using ESP32 DEVKIT V1 DOIT development board shown in Fig. 4. A DHT11 sensor was used to measure the temperature and humidity. A strain gauge load cell connected through the HX711 amplifier was used to monitor the mass of the product. Load cell supports, shown in Fig. 5, were created using a 3D printer. A relay was used to control the axial fan. It was used to turn on the fan when the humidity value exceeded 50% and vice-versa. The axial fan itself was powered by the solar panel. An SD card

module was used to record the data (temperature, humidity, and mass) into an SD card for 5 minutes. As the ESP32 board itself has Wi-Fi capabilities, it is used to develop the IOT-based remote monitoring system. The IOT-based system was powered by a power bank which provides a constant 5V DC supply. The components and circuit for the IOT-based system is shown in Fig. 6.

The coding for the IOT-based system was done using the Arduino IDE. The CP2102 driver and the ESP32 board package were used to connect the board to the IDE. The libraries used for the DHT sensor, load cell, Wi-Fi connectivity and Blynk software are 'DHT.h', 'HX711_ADC.h', 'WiFi.h' and 'BlynkSimpleEsp32' respectively. Similarly, 'FS.h', 'SD.h' and 'SPI.h' libraries are used for the SD card module. The code of this system is provided in the appendix.

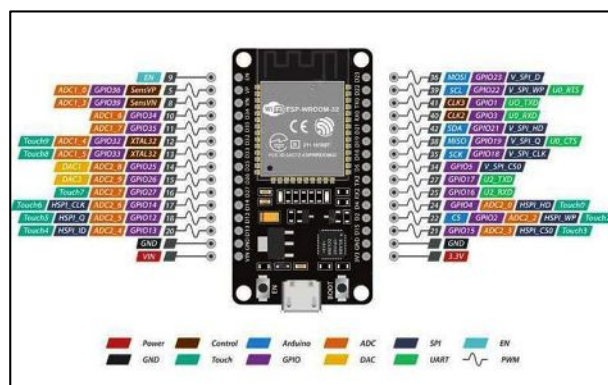


Fig 4: ESP32 Devkit pin layout



Fig 5: Assembly of the Load cell with base plate and the top plate

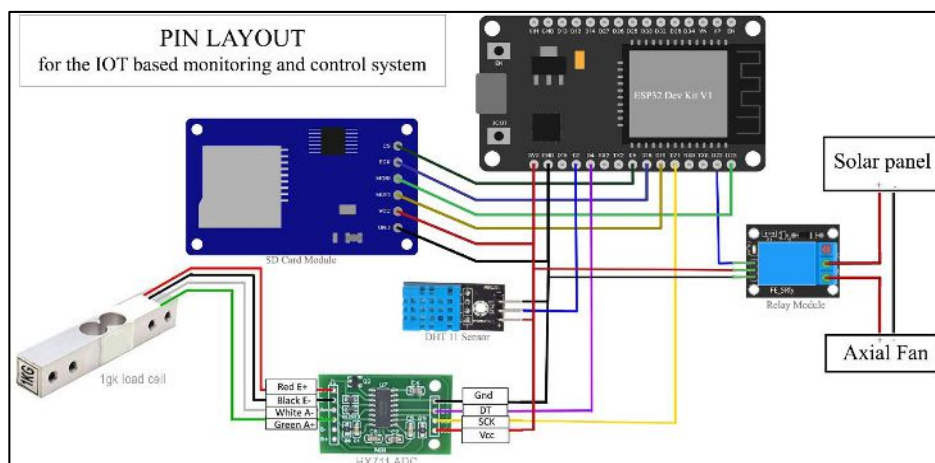


Fig 6: Pin layout for the IOT-based monitoring and control system

2.3 Development of Blynk dashboard for remote monitoring

Blynk is a cloud-based IoT platform that offers a suite of tools to build and manage connected hardware, mobile and web applications, data analytics, and user management. To create the dashboard, go to the website <https://blynk.cloud/> and register to create an account and log in. Go to

'Developer Zone' in the 'Blynk.Console' and select "+ New Template" option. Give a name to the template and select the appropriate device and connection type; as in 'ESP32' is the device and 'WiFi' is the connection type for this project. Create 'Datastreams' i.e., the type of data that is to be viewed on the dashboard, as shown in Fig. 7.

Id	Name	Alias	Color	Pin	Data Type	Units	Is Flow	Min	Max	Decimals	Default Value	Expose to Autom
2	Humidity	Humidity	Blue	V2	Double	%	false	0	100	##	0	CONDITION
3	Load	Load	Grey	V3	Double		false	0	1000	##	0	CONDITION
1	Temperature	Temperature	Red	V1	Double	°C	false	0	100	##	0	CONDITION
4	relay	relay	Dark Blue	V0	Integer		false	0	1	-	0	CONDITION

Fig 7: DataStream used in the project.

Go to the 'Web Dashboard' option and drag the required widgets from the various types of widgets available onto the dashboard. Then, choose the appropriate 'Datastream' that

the widget should display via the virtual pins. Fig. 8 shows the dashboard created for this project.

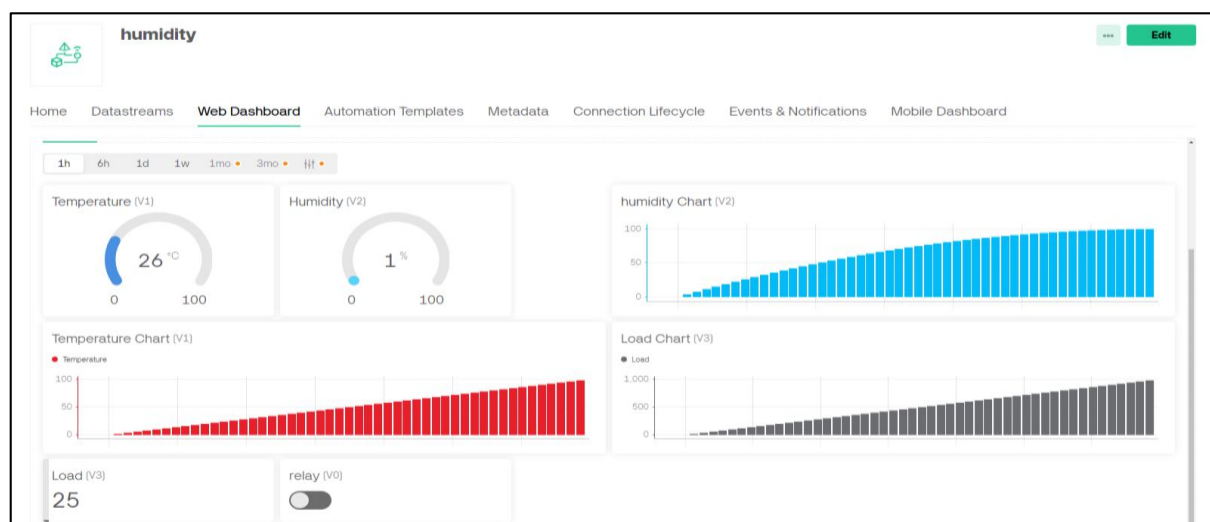


Fig 8: Dashboard design of the project

Save the template. Then, go to the 'Devices' menu in the 'Blynk.Console' webpage and create a new device using the created template. Then copy the 'Template ID', 'Template Name' and 'Auth Token' from the device options. Paste the 'Template ID', 'Template Name' and 'Auth Token' in the Arduino code. When the device is turned on and is connected to the Wi-Fi, the data as programmed in the code would be uploaded into the Blynk cloud. This data can be monitored remotely in the 'Blynk.Console', in the created device.

3. Results and Discussions

3.1. Cost of solar cabinet dryer

The solar dryer was fabricated with locally available material and the total cost of the cabinet dryer is Rs. 8830/-. The total cost details are shown in Table 1.

Table 1: The cost incurred for each material used in the fabrication of the solar dryer.

S. No.	Materials	Cost (Rs.)
1.	MS angular	500/-
2.	Aluminium angular	650/-
3.	GI sheet	2200/-
4.	Aluminium sheet	620/-
5.	Acrylic sheet	800/-
6.	Nuts and bolts	360/-
7.	Silicone	200/-
8.	Paint (with brush & thinner)	250/-
9.	12v BLDC fan	300/-
10.	Solar Panel	1950/-
11.	Welding and other miscellaneous costs	1000/-
Total Cost		8830/-

The cost details of the development of the IoT-based control system are shown in Table 2.

Table 2: The cost incurred for the components in an IOT-based control system

S. No.	Components	Cost (Rs.)
1	ESP32 DEVKIT V1	300/-
2	DHT 11	250/-
3	Load cell	260/-
4	HX711 Amplifier	40/-
5	SD card module	50/-
6	Relay	140/-
7	Jumper wires & header pins	150/-
	Total Cost	1190/-

Overall Cost for the development of the project model is Rs. 10020/-. The Retail price of the existing solar cabinet dryer

is Rs. 50, 000/-. So, compared to the existing dryer, the new dryer is very low cost and even includes the IOT-based monitoring and control system. The low cost of production is attributed to the use of locally available and cheaper materials for manufacturing the cabinet dryer.

3.2. IoT-based monitoring system using Blynk cloud software

The IOT monitoring system is used to monitor the temperature, humidity and mass of food products on the load cell. These parameter values are recorded by the respective sensors and uploaded to the Blynk cloud. These can be viewed either through the “Blynk.Console” webpage or on the Blynk mobile app. The developed Blynk dashboard in the website and mobile are shown in Fig. 9 and 10 respectively.

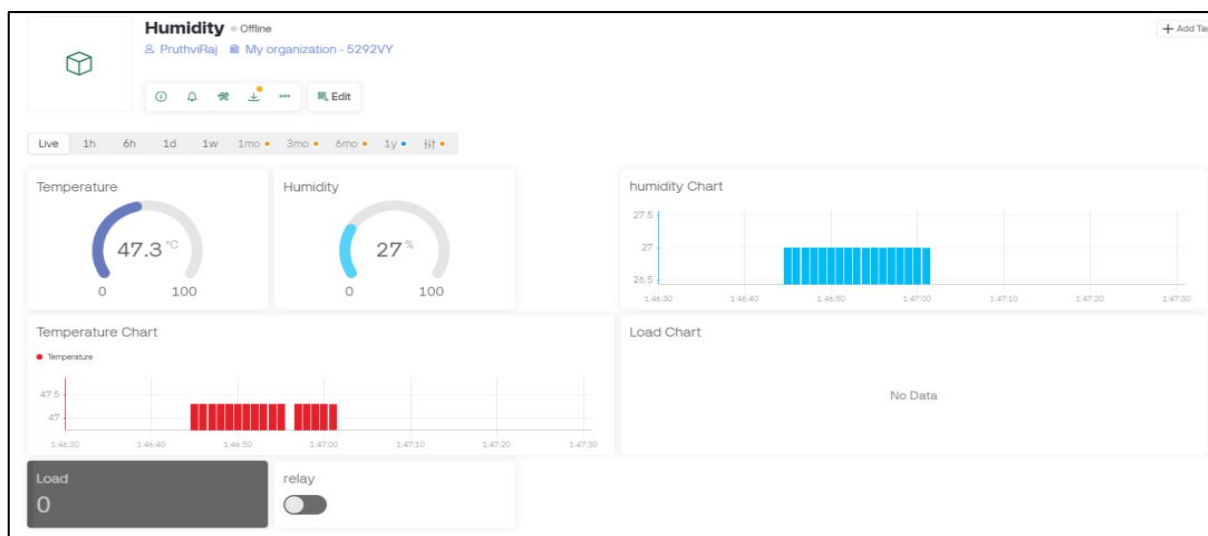


Fig 9: Monitoring system in the Blynk website on desktop

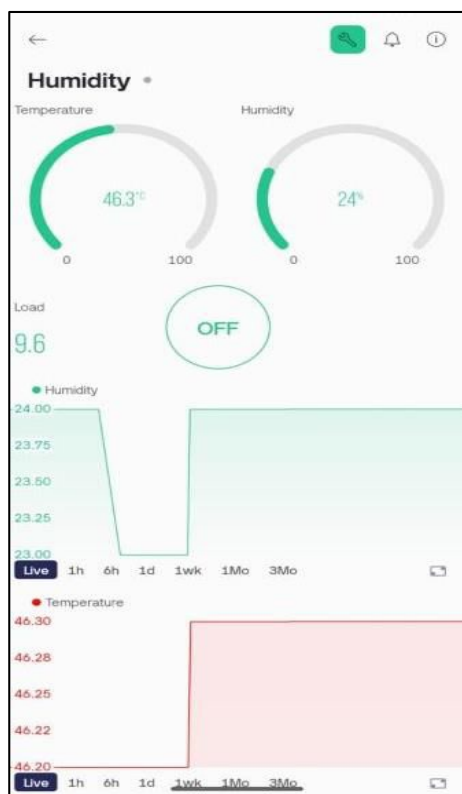


Fig 10: Monitoring system in the Blynk App on mobile

The data was also recorded in the SD card using the SD card module periodically every 5 minutes and was written into a ‘.txt’ file as shown in Fig. 11.

```

data.txt
File Edit View

Reading ID, Temperature, Humidity, Load
0,34.20,54.00,0.00
1,34.30,53.00,16.15
2,34.40,53.00,16.40
0,nan,nan,4335.63
1,34.50,53.00,7.53
0,34.70,59.00,1087.51
0,34.90,46.00,0.00
1,35.50,44.00,-2.86
2,35.60,43.00,-4.41
0,35.80,42.00,0.00
1,35.80,42.00,-7.34
2,35.80,42.00,-20.13
0,35.90,42.00,0.00
1,36.20,42.00,153.22
0,36.30,42.00,0.00
1,47.20,39.00,58.00
2,47.30,53.00,56.06
3,49.10,50.00,53.89
4,49.10,55.00,54.89
5,49.60,65.00,55.98
6,50.70,56.00,54.91
7,51.80,63.00,54.74
8,50.70,47.00,52.81
9,50.80,60.00,52.97
10,50.50,51.00,50.78
11,52.00,66.00,51.72
12,52.80,60.00,50.90
13,52.00,61.00,49.76
14,52.70,65.00,49.41

```

Fig 11: Sample of data recorded in the SD card

4. Conclusions and Summary

A low-cost solar cabinet dryer was fabricated based on the design of an existing solar cabinet dryer using low-cost locally available material namely, MS iron for frame and legs, GI sheet for walls and hatch, Aluminium bars for tray supports, Aluminium sheet for trays and acrylic sheet for top cover. Then, an ESP32-based monitoring system was developed to measure the temperature and humidity using the DHT11 sensor and mass of the product using a strain-gauge load-cell, inside the solar dryer, and then to record these values using a SD card module. ESP-based system was developed to control the forced circulation in the solar dryer based on the humidity in the dryer using a relay module. The system turns the blower of the developed dryer when the relative humidity inside it increases above 50% and turns the blower off when the humidity is below 50%. Then, an IoT-based monitoring system was developed using the Blynk cloud software. The temperature and relative humidity in the dryer and the mass of the product being dried were constantly measured and uploaded into the Blynk cloud, to remotely monitor these values through either the Blynk web page or through the Blynk mobile app.

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