

## A journey from vision to functionality: The IoT - integrated refractance window dryer's quest for smart drying perfection

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ARTICLE INFO	ABSTRACT
<p><b>Original Research Article</b> Received on February 28, 2024 Revised on March 20, 2024 Accepted on April 01, 2024 Published on April 19, 2024</p> <p><b>Article Authors</b> Harsh Dadhaneeya, Prabhat K. Nema</p> <p><b>Corresponding Author Email</b> <a href="mailto:hrshdadhaniya@gmail.com">hrshdadhaniya@gmail.com</a></p>	<p>The technique known as refractance window drying (RWD) has been recognized for its significant potential to dry commodities with higher quality at lower economic costs. This article outlines and describes an image of an RW dryer with Internet of Things (IoT) capabilities. This article has been created to serve as a blueprint for a future IoT based smart dryer. To preserve the product's quality and nutrient profile, the RW dryer includes an IoT-enabled temperature monitoring and control system. When it comes to producing fruit leather, many producers and farmers prefer to use the tedious and unpredictable open sun drying method, which significantly affects the sample's nutritional profile. This RW dryer with IoT connectivity is a sustainable and eco-friendly method of drying fruits and vegetables while reducing nutritional loss. IoT has transformed numerous sectors, and household appliances are no exception. One such invention is the IoT-based RW dryer, which aims to improve the effectiveness and user experience of conventional RW dryers. With increased energy efficiency, real-time monitoring, dynamic drying algorithms, and predictive maintenance, this smart dryer offers users with convenience, sustainability, and customized drying solutions.</p>
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<p>International Journal of Agricultural Invention (IJAI) <b>RNI:</b> UPENG/2016/70091 <b>ISSN:</b> 2456-1797 (P) <b>NAAS:</b> 4.56 <b>Vol.:</b> 9, <b>Issue:</b> 1, <b>Pages:</b> 29-35 <b>Journal Homepage URL</b> <a href="http://agriinventionjournal.com/">http://agriinventionjournal.com/</a> <b>DOI:</b> 10.46492/IJAI/2024.9.1.4</p>	<p>Refractance Window Drying, Internet of Things, IoT- Integrated, IR-Assisted RWD, Fruit Leather</p>

### HOW TO CITE THIS ARTICLE

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The drying of food is an ancient method for the preservation of food, and it has been a matter of significant research and development for decades, with an assortment of techniques for drying food having been invented, evaluated and implemented (Nemzer *et al.*, 2018). Refractance Window drying, an exceedingly most recent hydro-drying technique is marked by food exposure for a brief period of time. The RW drying system transports thermal energy to dehydrated materials by circulating water under a membrane (Baeghbali *et al.*, 2016).

RWD, usually referred to as conductive hydro-drying, is an incarnation of cast-tape drying (CTD) (Frabetti *et al.*, 2018). In the RWD process, thermal energy is transferred through conduction, convection, and radiation. An RW dryer tends to feature a membrane that enables the transmit of radiative heat while simultaneously serving as a protective barrier towards heating medium stimula (D. Shende and A. K. Datta, 2019). It's a fourth-generation novel approach since it transfers heat by convection, radiation, and conduction to dry the food.

Numerous researchers have recently reported studies of using RWD for producing finished dried products such as as malbhog banana (Dadhaneeya *et al.*, 2023), mango pulp (Zotarelli *et al.*, 2015), blueberry pulp (Rurush *et al.*, 2021), pomegranate juice (Baeghbali *et al.*, 2016), jamun pulp (Zhang *et al.*, 2024), apple slices (Subrahmanyam *et al.*, 2024), guava puree (Leiton-Ramírez *et al.*, 2020) and dragon fruit (Dadhaneeya *et al.*, 2023). The past lockdown epidemic scenario due to coronavirus is the best example that illustrates the necessity for dried high-shelf-life commodities that can be preserved for a long time (Dadhaneeya *et al.*, 2023).

Furthermore, there has been an upsurge in the popularity of ready-to-eat and highly nutritional food. Numerous studies have demonstrated that RW-dried food has better levels of nutrition, larger quantities of bioactive compounds and greater physicochemical properties; in the meantime, this drying procedure is both energy efficient and friendly to the environment. The proliferation of advanced technology and data-driven approaches has revolutionized several manufacturing processes in recent years. In the aftermath of the fourth industrial revolution (also called Industry 4.0 or IR 4.0), new technologies have sped up these transformations and digitally revolutionized aspects of the food sector (Echegaray *et al.*, 2022). "Industry 4.0" incorporates technologies such as advanced manufacturing, AI, big data analytics, block chain, cloud, IIoT and IoT (Bai *et al.*, 2020). Kevin Ashton developed the acronym "Internet of Things" (IoT) to refer to a tremendous network of digitally linked things and gadgets (Misra *et al.*, 2020).

The IoT is an infrastructure of interconnected objects and software that can transmit data without any human involvement (R. Badarinath and V. V Prabhu, 2017). The use of IoT has surged across all sectors in the past few decades. The IoT inspires food organizations to adopt a more inventive approach to acquiring an industry 4.0 outlook. This creates an abundance of new possibilities for food producers that adopt IoT solutions in the food sector in order to ensure the highest quality production, pinpoint inefficiencies in the supply chain, adhere to food safety regulations, and connect with customers (Dadhaneeya *et al.*, 2023).

The food sector is a prime candidate for the effective implementation of IoT in order to minimize or eliminate downtime caused by equipment failure or damage and to lower the cost of machine maintenance (Jambrak *et al.*, 2021). "Smart processing" and "smart manufacturing" are equally crucial as "smart farming" in addressing food production concerns, including efficiency, adverse effects on the environment, the safety of food, food quality, sustainability, and fulfilling global demands by boosting productivity. In the realm of food drying technology, the introduction of an IoT-enabled RW dryer marks a significant stride advance. IoT-connected RW dryers are a significant turning point in industrial drying operations, offering increased efficiency, control, and monitoring. Drying is an essential technique for the production of a wide variety of products.

The use of IoT-enabled dryers can result in significant gains in quality, cost-effectiveness, and sustainability. This advanced dryer provides unsurpassed control, simplicity, and effectiveness by combining the features of RWD with a smart IoT connection. Perks of merging IoT with RWD encompass smart control and monitoring, energy efficiency and data analytics, notifications and alerts, updates and remote troubleshooting, and enhanced food drying experience. IoT-enabled RW dryer serves as a groundbreaking gadget that amalgamates modern drying methodologies with state-of-the-art technological advancements. This fusion of novel concepts marks a significant step towards more sustainable and efficient gadget-making by simplifying the drying process while preserving the nutritional value of the dryer. The IoT insertion takes this appliance to the next level.

## Objective

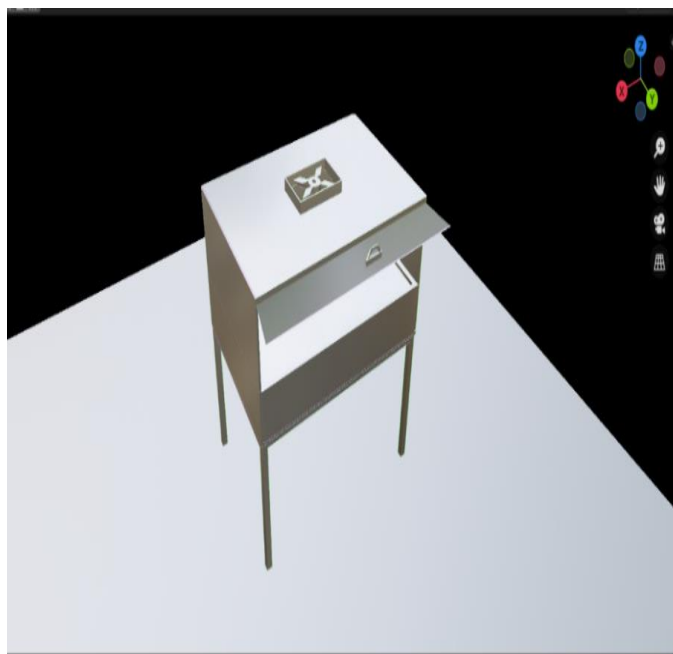
To design and develop IoT integrated RW dryer. This objective could potentially accomplish by bridging the research gap "There is a lack of extensive studies on the integration of IoT technology, particularly with refractance window dryers".

## Materials and Methods

### RWD

The design of RWD was made in blender 3.6.1.0 software. Stainless steel was used as the raw material because it has a substantially lower thermal conductivity than other metals, which helped reduce the energy lost due to heat transfer. A batch-type RWD with dimensions of 110 cm x 60 cm x 145 cm was fabricated and installed in NIFTEM-K. Dadhaneeya *et al.* (2023) article was the source of inspiration for both the design of this dryer and its operating concept. A simplified outline of the 3-D RWD structure is shown in fig 1. After successfully making engineering design of RW dryer, stainless steel material element successfully incorporates to dryer surface structure.

The methodology by which this operates is the same as MCD Technologies Inc. in Tacoma, Washington, USA, which constructed the first RW dryer. A layer of 0.25 mm in thickness made of mylar (also known as polyethylene terephthalate, or PET) was employed as the membrane. The decision to select the thickness of Mylar film, as proposed by existing literature data (Zotarelli *et al.*, 2015). The optical properties of the Mylar sheet are highly sensitive to even slight variations in thickness, chemical composition, and measurement technique.

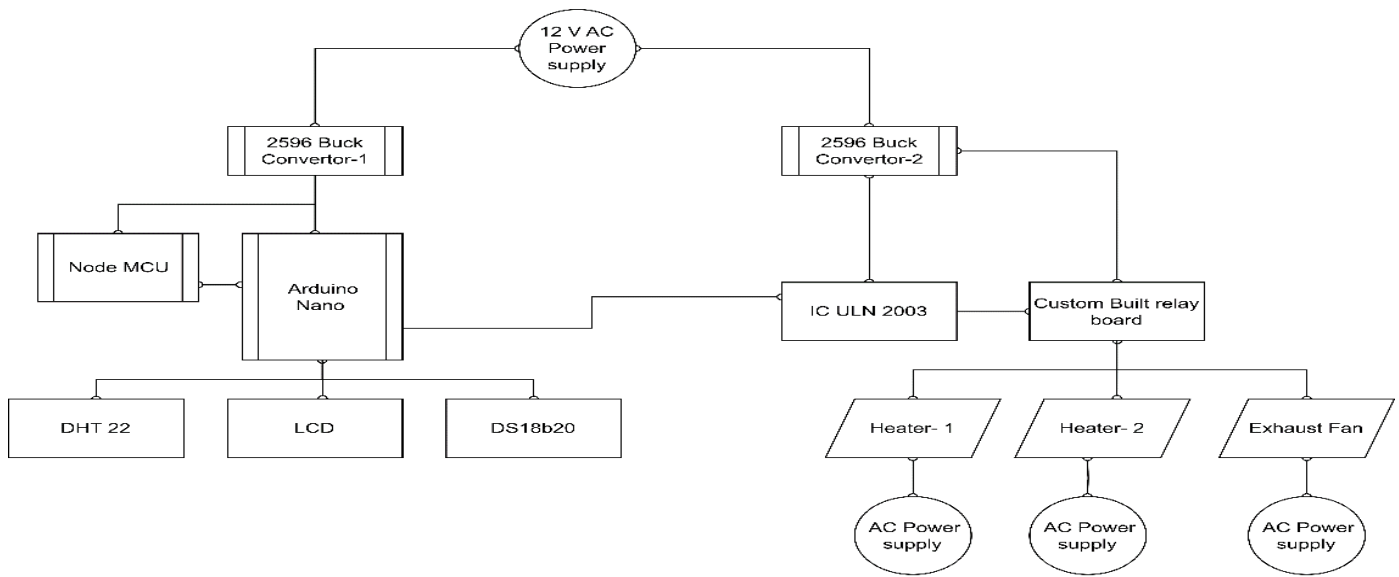


**Fig 1. Design of RWD by using Blender 3.6.1.0 software**

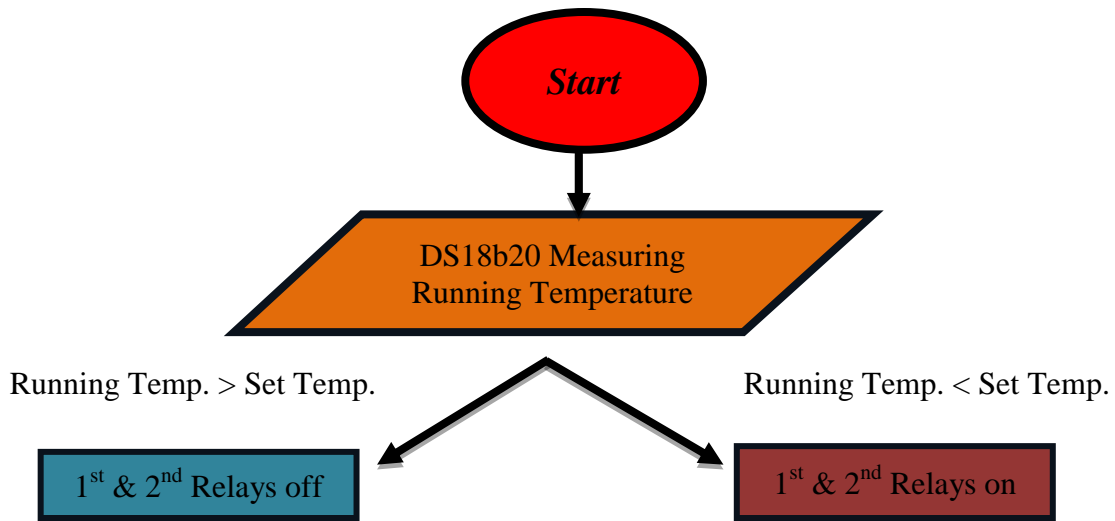
### IoT Circuit

Figure 2 illustrates the connection between the electronic components of an IoT device. A 12-volt, 2-ampere AC power supply was used as input in the 2596 buck converter, which produced 5 volts as output. In this case, two buck converters are employed. The 2596 buck converter-1 is linked to the Arduino Nano and the node MCU. The code for the Arduino Nano has been developed using the Arduino IDE 2.3.2 program. This code contains libraries, constants and variables, setup function, loop function, temperature reading, control logic, output control, delay and serial communication. Libraries contain pre-written code packages that offer additional features. The author uses "One Wire" libraries for this proposed IoT system. Constants are values that do not change throughout the program's execution; in this case, pin numbers were used as a constant. Variables are values that can vary during program execution; in this case, temperature readings and control signals are employed as variables.

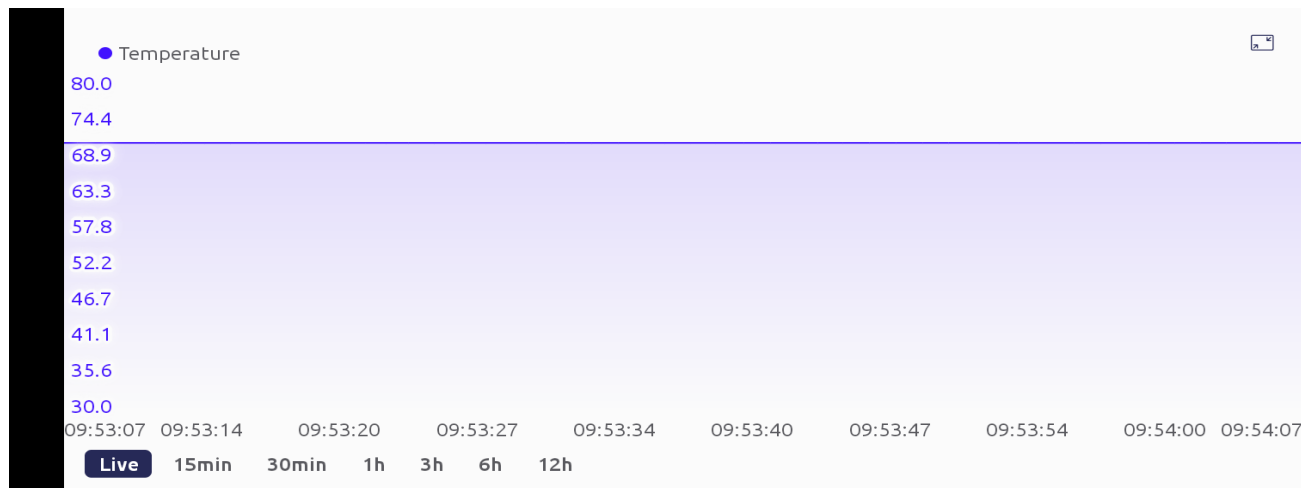
The setup function section of the code executes only when the Arduino is turned on or reset. The loop function is the main portion of the code that runs consistently as long as the Arduino is turned on. The temperature reading part involves obtaining the temperature data from a sensor linked to the Arduino. In the control logic section, decisions are made based on temperature readings. The output control section of the code transmits signals that control external devices. Delays can be used to regulate how frequently the temperature is measured and actions are made. It generally reads sensor data, processes it, and then takes actions depending on it. The Arduino Nano and the Node MCU were interconnected through Tx and Rx. In this circuit, two temperature sensors are utilized. These two sensors, DS18B20 and DHT 22, connect to Arduino Nano. 2596 Buck convertor-2 is connected to an IC ULN 2003 amplifier and relay board. And this IC ULN 2003 amplifier is additionally connected to Arduino Nano. A relay board serves to link the heater and exhaust fan relay-1 and relay-2 were connected with heater-1 and heater-2.



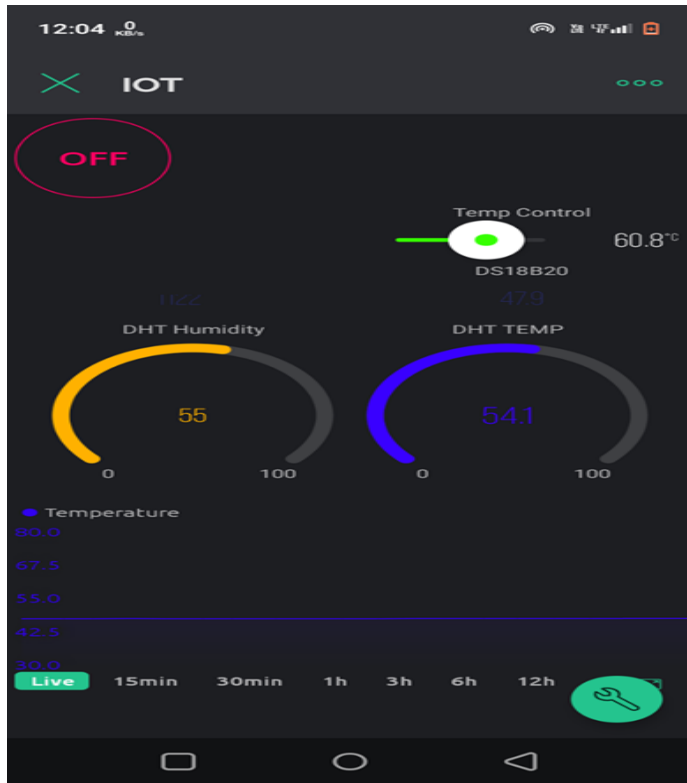
**Fig 2. Electronics component connection**



**Fig 3. Predefined operating context diagram**



**Fig 4. Blynk IoT app's Temperature vs Time graph**



**Fig 5. Blynk IoT application Interface**

## Results and Discussion

The IoT-enabled temperature monitoring system was installed in an RW dryer structure, where temperature control was essential for ensuring product quality and equipment safety. The precision and reliability of the collected data were crucial aspects of the IoT-enabled temperature monitoring and controlling system. Multiple calibration tests were conducted to ensure the accuracy of the sensors, which led to negligible measurement errors within the acceptable range. The system's real-time monitoring effectiveness proved advantageous when spotting temperature abnormalities. Fig 3 illustrates the diagram of the predefined operating context. In this system, the DS18B20 temperature sensor was used to monitor the temperature of the mylar layer. This sensor's usable temperature range was -55 to 125°C. Whenever the temperature exceeded predefined thresholds, the system automatically switched off relays 1, 2 and if the temperature succeeds predefined thresholds, the system automatically switched on relays 1 and 2. In this system, the DHT 22 sensor observes humidity. The humidity parameter was only used for monitoring purposes and could not be controlled in the proposed system.

However, the user can operate the relay-3 manually when humidity levels fall outside the predetermined limits. Durani *et al.* (2018) and Serikul *et al.* (2018) were the source of inspiration for using IoT with the Blynk App. Fig 5 displays the screenshots of the outcomes obtained from the Android application of the designed system. The relay board may be controlled from any distant place using the smartphone's virtual button, which the user can press by tapping on the button. The slider button (depicted in green) does for the set temperature. The first dial gauge (depicted in orange) allows the user to monitor humidity, and the second dial gauge (depicted in blue) is used to monitor temperature. And below that dial gauge temperature vs time graphs were depict. This full illustration given in fig 4 in that graph interface user can monitoring live temperature, 15 minutes, 30 minutes, 1 hr., 3 hr., 6 hr. and maximum of 12 hr. temperature. By observing this continuous straight line of temperature, one may deduce that this IoT-integrated controlled system works efficiently and that the proposed technique for drying works effectively, which can fulfill the primary predefined objective of this research work.

## Conclusion

The approach through which the IoT-integrated RW dryer went from an idea to a functioning product has been nothing short of revolutionary. It has completely revamped the drying procedure and established brand-new benchmarks in the field of intelligent drying. The current study sought to leverage IoT technology to monitor and control the temperature of RWD. This article examined the development and implementation of this cutting-edge IoT technology with 4th-generation drying technology, emphasizing its numerous innovations and remarkable accomplishments. From ideas inception as an imaginative way to exploit the abilities of the RW dryer, this novel idea rapidly evolved into a comprehensive solution that addressed key challenges encountered by conventional drying methods. The IoT-enabled refractance window dryer demonstrated its capacity to deliver precise and controlled drying results throughout its voyage. Operators could monitor vital drying parameters in real time by carefully placing sensors inside the drying chamber.

This level of data accuracy enabled them to make intelligent decisions, ensuring superior and consistent product quality while minimizing waste. As industries continue to adopt smart technologies, the near future contains even more potential for the IoT-integrated refractance window dryer, heralding a new era of efficient, sustainable and intelligent drying solutions for the entire world.

### Novelty of Article

The design of IoT-integrated refractance window drying studies is essential because of their potential for transforming industrial drying processes. By integrating IoT technology with refractance window dryers, researchers may push the boundaries of process optimization, real-time monitoring, and data-driven decision-making. These investigations enable the development of new techniques and control systems that take advantage of IoT connections to increase drying efficiency, product quality. Furthermore, such research enables the exploration of innovative sensor technologies and data analytics methodologies designed particularly for the problems of drying applications. Through methodical examination of the engineering design consequences associated with the IoT integration in RW dryers, researchers can uncover novel perspectives that facilitate the extensive implementation of these modern drying technologies in various sectors, leading to enhancements in efficiency, eco-friendliness and competitiveness. Furthermore, these research investigations open the door to the widespread adoption of leading-edge drying technologies, encouraging ongoing advancement and competitiveness in manufacturing sectors across the globe by assessing the economic viability and scalability of IoT-integrated drying systems across a range of industrial applications.

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