

Smart Safe Dryer for Handloom with Controlled Humidity, Temperature and Airflow

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Abstract

Handloom weaving involves repeated wetting of yarn during saree production to maintain stiffness and alignment. However, the subsequent drying process is typically performed using natural air or handheld devices, leading to uneven moisture removal, increased drying time, and potential fabric damage. This work proposes a compact and safe drying assistance system designed specifically for handloom environments. The system utilizes controlled airflow generated by a cooling fan combined with a low-temperature Positive Temperature Coefficient (PTC) heating element to enhance evaporation without exceeding safe thermal limits for silk and cotton fabrics. Temperature and humidity sensors continuously monitor the fabric microenvironment, enabling automatic cut-off once the desired dryness threshold is achieved. The prototype demonstrates uniform drying, reduced manual effort, and improved operational efficiency compared to traditional methods. The proposed solution provides a low-cost, loom-integrated approach that enhances productivity while preserving fabric integrity and traditional weaving practices.

Keywords: Handloom weaving, saree drying, textile processing, temperature control, humidity monitoring, embedded systems

1. Introduction

In rural textile production, handloom weaving is still a crucial element, particularly in the production of silk and cotton sarees. Wetting the yarn with water at intervals is used to prevent thread from breaking, improve stiffness, and ensure thread alignment during weaving. This is a unique process. Repetitive wetting can introduce moisture that must be eliminated before weaving can proceed as intended. Studies on heat and moisture transfer reveal significant changes in woven fabrics due to excess humidity, which has an immediate impact on thermal resistance and drying behavior, as well as mechanical stability. Experimental evidence indicates that fabric wetting has a significant impact on thermal comfort and surface cooling characteristics, underscoring the importance of controlled drying conditions [3, 4].

The use of controlled airflow and temperature control in industrial textile drying systems is often unsuitable for small handloom settings due to their large size, high cost, and poor performance. Handloom practices that utilize natural air drying or handheld heating devices result in uneven moisture loss and potential fabric damage. In order to overcome this inadequacy, the study proposes utilizing a drying aid system that

utilizes controlled warm airflow from alternating rotations of varying sizes created by an industrial cooling fan and screened by another safe heating element.

2. Literature Survey

Heat and mass transfer principles have played a significant role in the study of textile drying. Wet woven fabrics thermal resistance and evaporation properties are significantly influenced by moisture, leading to alterations in drying speed and structural stability [4], [5]. Despite the importance of controlled drying temperature and airflow, fabric wetting is also linked to surface cooling behavior and heat dissipation patterns in experimental studies. [3]. Several IoT-based drying rack systems have been suggested in recent years to automate moisture detection and drying control. Efficiency improvements have been observed in smart drying lines that use microcontrollers and humidity sensors, enabling automated ON/OFF mechanisms that adjust to environmental conditions [1], [2]. Intelligent drying rack systems that incorporate temperature and humidity monitoring have been proven to be effective in controlling moisture for small-scale household

applications. [6]. Investigations into conductive textile heating suggest that temperature-controlled heating elements are essential to prevent the degradation of delicate fabrics like cotton and silk.[1]. Even so, most systems currently in use are designed for industrial or domestic use and do not address drying during handloom weaving. The literature allows for the development of a drying assistance system that is compact and designed to support conventional handloom labor.

3. Methodology

3.1. System Design Principle.

Heat and mass transfer in wet textile materials are the foundation for the proposed drying assistance system. During weaving, the inter-fiber spaces become saturated with moisture due to wetter conditions, which affects thermal resistance and inhibits evaporation. Research has shown that wet-state thermal resistance is an important determinant of fabric behavior and drying rate.[4]. Furthermore, wetting fabric alters surface cooling characteristics and evaporation patterns through experimentations, underscoring the importance of controlled drying over uncontrolled heat [3, 4]. In contrast to industrial textile drying systems that rely on high-capacity blowers and excessive temperatures unsuitable for handloom conditions [1], [2], the current design is designed in a low-power, loom-integrated, compact form. They hope to improve drying efficiency while preserving fabric safety and traditional weaving practices.

3.2. Airflow Generation and Heating Mechanism.

Drying is mainly achieved through forced convection. The fabric surface of the saree is evenly distributed with an integrated cooling fan that runs along its entire width. By reducing the thickness of the boundary layer over this moist fabric, forcing it in will accelerate moisture removal and speed up the process (as opposed to natural air drying). The use of a low-temperature Positive Temperature Coefficient (PTC) heating element is intended to prevent damage to silk and cotton fibers by promoting evaporation. This means that the temperature is kept within the unit, not by a fan or fan-like mechanism. Research on conductive textile heating systems highlights the need for temperature-controlled heating to prevent thermal degradation of fibers [8]. By utilizing both

moderate heating and uninterrupted airflow, the system achieves an even and balanced drying process for the entire saree width.

3.3. Sensor Integration and Control Strategy.

Temperature and humidity sensors installed near the fabric surface enable real-time monitoring. Several drying rack systems that incorporate IoT technology have successfully utilized sensor-based control strategies to detect moisture levels and automate drying operations. The microcontroller continuously reads sensor data and processes it to determine the drying state. Once the system has been set up by hand, it will activate the cooling fan immediately and then heat it up with regulation. As the drying process continues, relative humidity near the fabric decreases. When the humidity level falls below a predetermined threshold, which indicates sufficient moisture removal, the microcontroller activates the heater and fan by means of relay modules. The automatic cut-off mechanism is ideal for continuous handloom weaving operations, as it avoids over-drying, conserves energy, and delivers consistent drying results. Figure 1 Shows Block diagram of the system

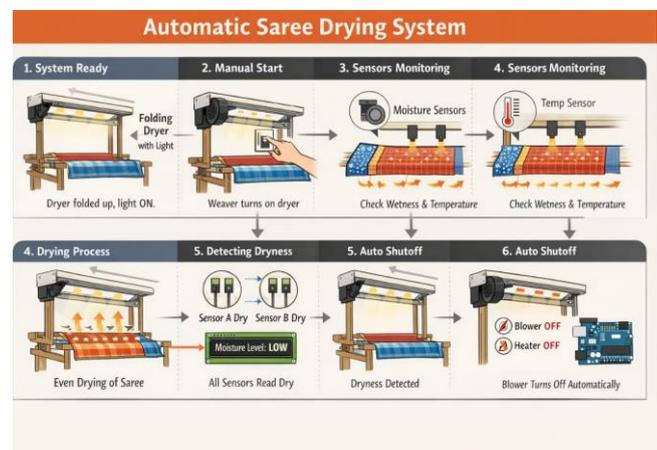


Figure 1 Block Diagram of the System

4. Hardware Setup

A compact, safe and compatible hardware implementation for the proposed smart drying assistance system is designed to accommodate existing handloom structures. An Arduino UNO or ESP32 microcontroller is the central control unit, which manages sensor data and system operation. The saree's surface is equipped with temperature and humidity sensors that can monitor the environmental conditions that affect moisture evaporation in real-

time. Using sensor-based monitoring methods, drying rack systems with IoT capabilities have been successfully utilized to automate drying decisions [6], [7]. The saree's width is parallel to the height to ensure even airflow with a cooling fan. In contrast to high-power industrial blowers used in large textile drying systems, the fan chosen is low-powered and appropriate for small-scale weaving environments. The drying efficiency is improved by the use of a Positive Temperature Coefficient (PTC) heating element, which provides controlled and self-regulated heating. Research on textile heating systems emphasizes the importance of regulating temperature to prevent fiber degradation and maintain fabric integrity [8] Figure 2 Shows Block diagram of the hardware components

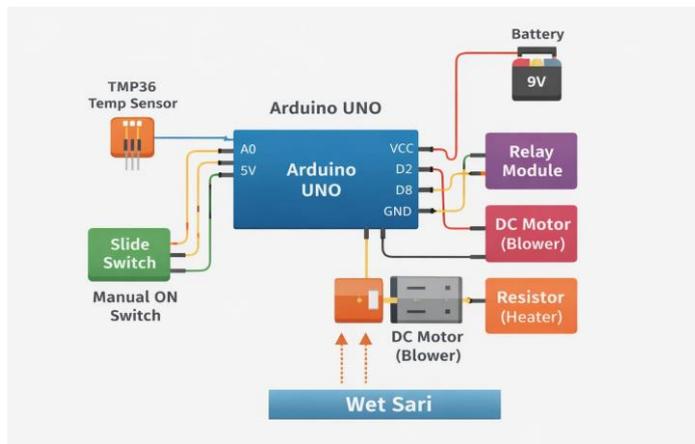


Figure 2 Block Diagram of the Hardware Components

Safe and electrical isolation are ensured by the use of relay modules that control power supply to the fan and heating element. Power supplies are kept separate from each other for the control and heating circuits. The hardware configuration guarantees secure integration into traditional handloom workflows, consistent drying, and reliable operation. 1.1. Table. Shows Hardware components list

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Hardware Components

Component	Specification	Purpose
Arduino UNO/ESP32	5V logic, 16 MHz/ 240 MHz	Control unit
DHT22	Temp&RH sensing	Moisture monitoring

Cooling Fan	12V DC	Uniform airflow
PTC Heater	Self-regulating	Controlled heating
Relay Module	5V Trigger	Switching heater & fan
Power Supply	12V DC	System power

Results and Discussion

5.1 Results

The developed prototype was tested under controlled indoor conditions on wetted silk and cotton saree sections. The system successfully reduced drying time compared to conventional natural air drying. Forced convection generated by the cooling fan enhanced evaporation by reducing the moisture boundary layer over the fabric surface, which is consistent with established heat and mass transfer behavior in wet textiles [4], [5]. The relative humidity near the fabric surface decreased steadily from high initial values (>70%) to the predefined threshold (<45%), at which point the system automatically switched off. This confirms the effectiveness of sensor-based moisture detection similar to previously reported IoT-enabled drying rack systems [6], [7]. Temperature readings remained within safe operating limits due to the self-regulating characteristics of the PTC heating element. This prevented overheating and maintained fabric integrity, which aligns with temperature-controlled textile heating studies [8]. Uniform airflow distribution across the saree width resulted in consistent drying without localized wet patches.

5.2 Discussion

The results indicate that controlled airflow combined with mild heating significantly improves drying efficiency over traditional handloom drying methods. Previous studies highlight that wet fabrics exhibit altered thermal resistance and evaporation characteristics [4], [5], making uncontrolled drying methods inefficient. The experimental findings support these principles, demonstrating that forced airflow accelerates moisture removal while maintaining structural stability. Unlike industrial textile dryers designed for bulk processing [1], [2], the proposed system offers a compact and loom-integrated solution tailored to handloom

environments. The integration of humidity-based automatic cut-off prevents over-drying, reduces energy consumption, and enhances operational safety. Furthermore, fabric wetting studies show that uneven moisture removal affects cooling and surface behaviour [3]. The uniform drying achieved in this system addresses that limitation. Overall, the system bridges the gap between textile drying theory and practical handloom application. Figure 3 Shows Block diagram of the working model

overheating delicate silk and cotton materials. The system is designed for handloom conditions, unlike industrial textile drying systems that are intended for large-scale operations [1], [2,] and requires minimal power consumption. Sensor-based IoT drying solutions have been reported in recent literature [6], and the use of temperature and humidity sensors allows for real-time monitoring and automatic cut-off. Also, the utilization of a self-regulating PTC heating element is consistent with textile heating safety guidelines to prevent fiber damage [8].

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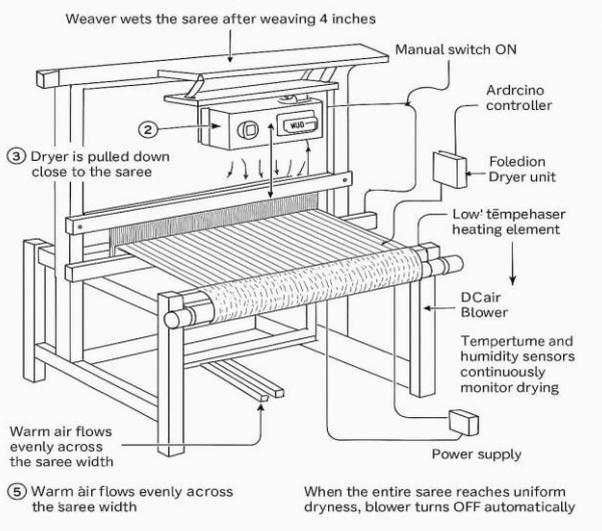


Figure 3 Block Diagram of the Working Model

Also, fabric wetting experiments demonstrate that uneven moisture absorption can alter the cooling and surface behavior. [3]. That limitation is overcome by the system's ability to dry uniformly. In essence, the system links the theory of textile drying with practical implementation on handlooms.

Conclusion

The proposed smart drying assistance system is both compact and practical in facilitating the drying of saree fabrics during handloom weaving. Utilizing heat and mass transfer principles for wet fabrics [4], [5], the system employs controlled airflow with regulated heating to increase fabric durability through improved fabric evaporation. It has been established that fabric wetting has a significant impact on thermal behavior and cooling characteristics, necessitating precise drying to avoid structural damage. A prototype was implemented that ensured uniform moisture removal across the saree's width without

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