Prototype Development of a Real-Time Monitoring System Based on Android and Cloud Database for Textile Non-Thermal Plasma Treatment

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ABSTRACT

The textile modification process using plasma treatment requires accurate monitoring of gas species generated during operation; however, no system is currently available to measure these gas concentrations in real time. To address this gap, this study develops a plasma gas monitoring system for textile material modification, using experimental data obtained from laboratory tests conducted in 2024. The research employs a practical prototyping approach consisting of four stages: requirement identification, system design, prototype construction, and performance validation. The system is designed to continuously record plasma-generated gas concentrations and store the data in an internet-based database. The prototype consists of two main components: (1) a sensing unit built on an Arduino Uno microcontroller integrated with DHT-11 and MQ-131 sensors for measuring temperature, humidity, and ozone concentration, and (2) a data management platform using Google Spreadsheet connected to a mobile application to enable real-time monitoring and control. Evaluation results show that the monitoring tool achieved a Mean Absolute Error (MAE) of 0.6625 ppm, indicating that the system provides reasonably accurate measurements for initial validation. As this assessment is preliminary, future studies should employ a larger dataset to increase statistical robustness and further verify system performance. Overall, the findings contribute to the development of an accessible, Android-based plasma treatment monitoring system capable of supporting real-time monitoring in textile material modification applications.

1. Introduction

Rapid technological growth is consistent with the Industrial Revolution 4.0 agenda, which emphasizes automation, the integration of the Internet of Things (IoT), and artificial intelligence in various aspects of life, particularly in the industry [1], [2], [3] These improvements promote the transformation of tools and procedures to better adapt to usage situations and boost process efficiency. One key change happens in the reporting and information system, as it transitions from traditional paper-based procedures and direct physical communication to a more effective and efficient digital approach. Monitoring systems based on database integration and real-time reporting, which employ the internet and smart devices, are one of the most common methods for increasing user flexibility [4].

Several studies have demonstrated the successful deployment of integrated information systems for monitoring activities, tools, and control systems using microcontroller technology, Android devices, and IoT [5], [6], [7]. These systems have been widely applied in logistics, business, research, and education [8], [9], [10]. A similar opportunity exists for supporting non-thermal plasma treatment in the textile industry. Non-thermal plasma utilizes electric fields and physical processes to generate active gas species capable of modifying the molecular structure of textile surfaces [11]. Previous investigations have confirmed the effectiveness of non-thermal plasma in altering textile characteristics [12], [13], [14], [15], [16], [17], [18]. However, these studies primarily focused on material outcomes and did not measure the concentration of plasma species produced during treatment.

Real-time monitoring is essential because the concentration of plasma-generated species fluctuates dynamically in response to changes in voltage, electrode distance, and exposure duration. These variations directly influence the uniformity, effectiveness, and reproducibility of surface modification results. Without real-time data, operators cannot determine whether the plasma is generating sufficient reactive species or deviating from optimal conditions, which may lead to inconsistent treatment outcomes or energy inefficiency. Therefore, developing a real-time monitoring system is necessary to identify optimal operating parameters and ensure stable plasma performance during textile modification processes.

Therefore, an integrated information system is needed to monitor plasma species using mobile phone media as a flexible control device and database for real-time recording of plasma gas concentrations. The monitoring system development technique with the evaluation, such as MAE, might use the prototyping process, which consists of the stages of requirements collecting, design ideation, prototype, and evaluation [19], [20], [21], [22], [23], [24], [25]. These steps ensure that the system operates properly and that the tool is developed to its greatest potential.

The goal of this study is to address the absence of real-time gas species monitoring tools in non-thermal plasma applications for textile processing. To close this gap, the study develops an integrated monitoring system that links sensor-based plasma species detection with a mobile interface and a cloud-based real-time database. This system is designed to support more consistent and efficient plasma treatment by enabling precise, continuous, and adaptable monitoring during textile modification processes.

2. Methods

This study adopted a prototyping methodology, which is suitable for developing a hardware–software monitoring system that requires iterative refinement based on real-time testing. The prototype development involved clearly defined inputs, processes, and outputs. The input consisted of operational requirements for plasma treatment, target plasma species to be monitored, and sensor specifications needed for detecting temperature, humidity, and ozone concentration. The process stage included system design, microcontroller programming, sensor integration, data transmission setup, and prototype fabrication using an Arduino Uno, DHT-11 sensor, MQ-131 sensor, and supporting electronic modules. Additional supporting tools, such as a plasma generator, power supply, testing chamber, and calibration instruments, were used to validate sensor performance under controlled plasma conditions. The output of the prototyping process was a functional monitoring device capable of capturing real-time plasma gas data and transmitting it to a cloud-based database accessible through a mobile application. Figure 1 illustrates the complete research framework applied in this study.

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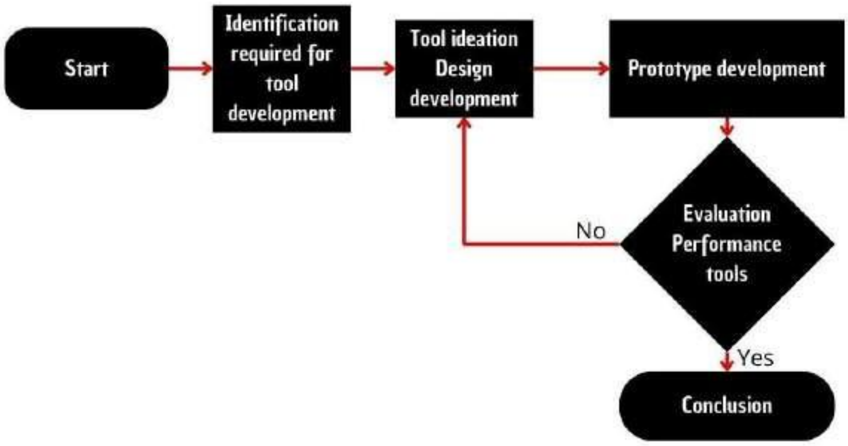

Figure 1. Framework Research

a. Identification Required for Tool Development

This process involves brainstorming related to the functional, design, and technical needs of the tool with non-thermal plasma users, especially students and lecturers, as researchers in this field. The research sample used also as respondents chose several researchers who came from the internal institution of Politeknik STTT Bandung, who specifically used non-thermal plasma equipment in the basic physics laboratory of Politeknik STTT Bandung.

b. Tool Ideation, Design Development

At this stage, the acquired data demands are turned into a design, which is created using SketchUp software, which is a software-aided design tool that describes the simulation of the tool in a three-dimensional image.

c. Prototype Development

At this stage, the simulation tool's design is converted into a small tool known as a prototype. Prototyping tools and materials include acrylic with a thickness of 3 mm used as a tool casing, project board used as a circuit media, arduino uno used as a microcontroller, MQ 131, DHT 11 sensors used as parameter sensors, jumper cables and adapter cables used as electrical conductors, and computer devices equipped with arduino ide software and mit app inventor android devices for tool programming. All of these materials are employed and will be examined for performance evaluation using specific test procedures [21].

d. Evaluation Performance Tools

At this level, the tool is examined using the behavior validation approach. The behavior validation test is performed by comparing sensor output data to data obtained from validated instruments or the results of an earlier study conducted in the same city location.

3. Results and Discussions

The results of this study include the implementation of a prototyping approach that starts from identifying needs, building design ideation, building prototypes, to evaluating the performance of prototype tools.

a. Identification Required for Tool Development

Identification of the needs for the formation of tools is done by brainstorming with three researchers, represented by lecturers and students. Table 1 shows the results of the development of the non-thermal plasma monitoring tool needs.

Table 1. Result tools need development, and monitoring tools

Functional	Design	Technical Needs
Real-Time Displays Monitoring	Graphical user interface (GUI) with a real-time dashboard.	Sensor data integration, high-speed data processing on Android device applications
Real-Time Record Data in Database	A backend system to store data automatically	Database management system (DBMS)
Real-Time Control	Control panel with buttons and status indicators	Microcontroller, real-time operating system in Android device
Easy for maintenance activity	Modular design for easy component access	Standard interfaces, diagnostic tools
Easy for an overhauled activity	Design that can be quickly disassembled	Quick-release mechanisms, modular components
Easy to improve the listing program	Flexible and documented code architecture	Version control system (e.g., Git, modular programming

According to Table 1, there are six development points required to design a monitoring tool. Respondents feel that the tool can present parameter data in real time, implying the necessity for a graphical user interface (GUI) with a real-time dashboard displayed on the tool. Monitoring tools make use of Android smartphones that are equipped with monitoring programs designed to meet technological criteria such as sensor data integration and dependable data transmission speed. Respondents also requested that the displayed data be recorded in real time in the database; therefore, the tool must include a database backend system that enables data collection and storage via penetration with real-time delivery. As a result, a database management system was implemented using an open-source database. Respondents also considered the need for a button that can be controlled remotely in real time. This is based on the non-thermal plasma, which is built using a high electric voltage, so that the monitoring parameters must be turned on within a safe radius of the device. As a result, the application design allows for button tools in the interface as a remote controller of the current monitoring system.

According to respondents, the physical needs of the tool must also allow for ease of rejuvenation and maintenance of the tool, including maintenance and overhauling activities, in which case the design and technical tools are formed to facilitate this activity because this activity is carried out on a regular and routine basis, so the ease of the process must also be one of the primary reasons. Respondents also noted the need for a listing program that includes modifications in conversion features and easily changeable units of measurement. As a result, via design and technical means, a module is used to accurately capture the process of listing programs, including written and video modules.

b. Tool Ideation, Design Development

The design is separated into two parts: physical design, which includes the tool casing and the arrangement of various components, and program design, which includes the application interface and database. Figure 2 illustrates the basic operation of this instrument.

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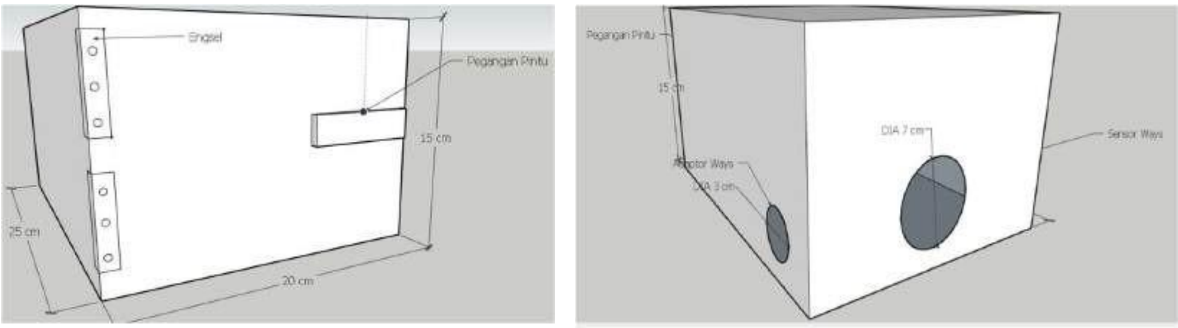

(a) Casing Front View (b) Casing Back View

Figure 2. Physical Design

The physical design area (Casing) is created according to the dimensional requirements of the equipment, which includes microcontrollers and project boards. The casing also features door supports and hinges to facilitate cleaning of the instruments inside. Meanwhile, the hole diameter was designed to enable cable routing for both the power supply and sensors linked to the non-thermal plasma treatment apparatus. Meanwhile, Figure 3 shows the interface design of the resulting mobile phone application.

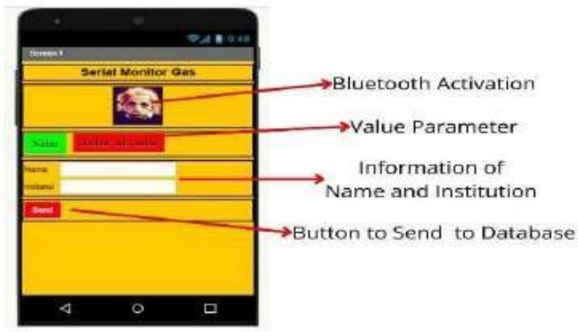

Figure 3. Design Interface Android

The serial monitor device for Android devices is designed with user convenience in mind, which includes connecting the tool to the installed Android device, displaying the parameter values read, and reporting columns for the name and agency of the researcher who uses it to send all of the information to the database. The activation button with the Albert Einstein logo was chosen to make it easier to find the Android device activation button and link Android smartphones to monitoring sensors. This application also includes a monitor display, which displays the detected parameter values as well as information about the user's name and linked institutions. Furthermore, the application includes a transmit option, which allows monitoring data to be transferred to a database. This "Send" button sends information about the user's identity and institution to the monitoring program as a means of recording non-thermal plasma treatment users.

c. Prototype Development

The physical design of the casing and Android software that has been made is then physically formed, which is complemented by the assembly of the sensor circuit and microcontroller, as shown in Figure 4. The sensor circuit must be positioned into the physical casing that is formed with reference to the layout shown in Figure 5 to facilitate maintenance and overhaul needs later. Meanwhile, the working principle and concept of using the device are shown in Figure 6, which serves as a guide in understanding how the monitoring device works to observe plasma parameters. Meanwhile, Figure 7 shows the final result of the physical design as well as the device test process when the plasma system is operated. This figure also displays the open-source spreadsheet database page that records monitoring data in real time.

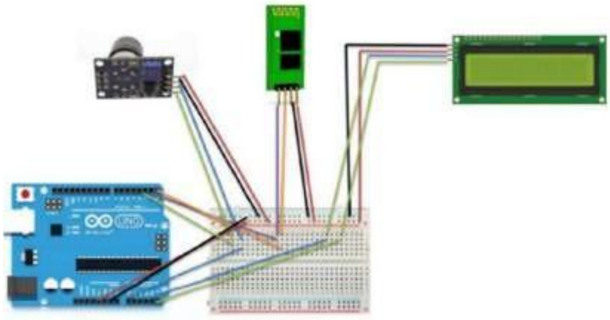

Figure 4. Design Sensor Circuit

Figure 4 shows the assembled MQ-131 and DHT 11 gas sensors, Bluetooth serial communication module, and LCD I2C display. This design allows the installation of the sensor components into the microcontroller with proper and appropriate connection lines. The MQ-131 sensor is highly sensitive to ozone and nitrogen dioxide gases, which are the main indicators of the gases formed during the plasma process. The Bluetooth serial communication module serves as the link between the sensor and the Android device, allowing data transmission wirelessly. Meanwhile, the I2C LCD is used to display the parameter readings directly on the screen. The display on this LCD also acts as an indicator that the device is functioning and running properly.

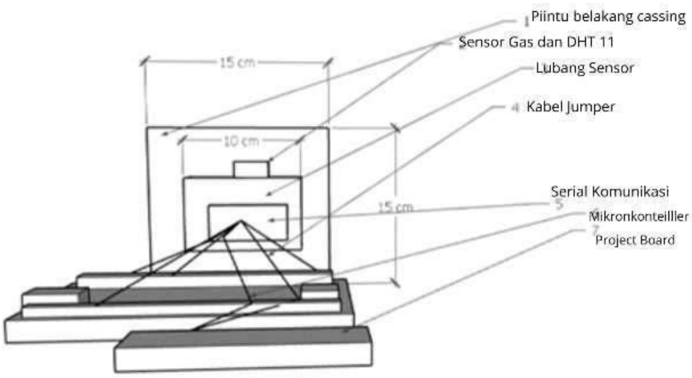

Figure 5. Tools Layout Design

The layout shown in Figure 5 is designed to facilitate maintenance and overhaul. The placement of the microcontroller in the center of the case aims to facilitate connectivity with both the power source and the connected sensors. In addition, the position of the microcontroller's power supply towards the side hole of the case facilitates the process of updating or reprogramming the device, as well as facilitating access to the power supply. Sensors are placed in specific hole positions that lead directly to the non-thermal plasma gas formation chamber, so that plasma process parameters can be detected and read optimally.

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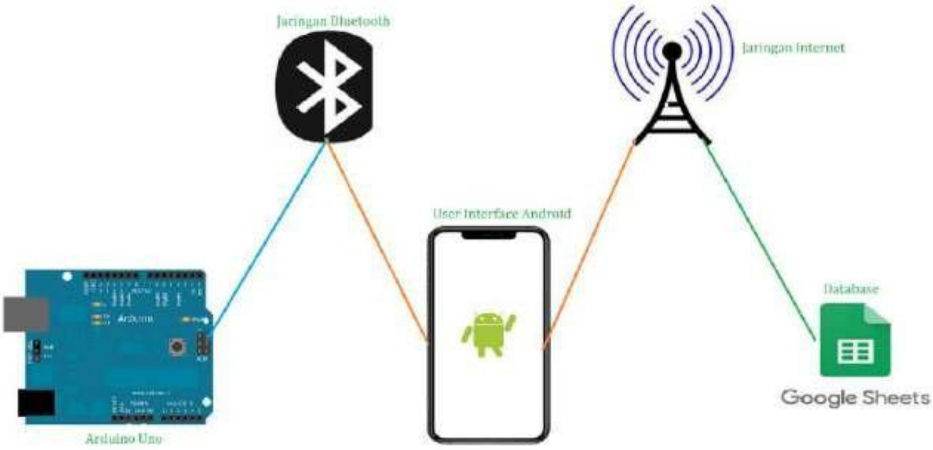


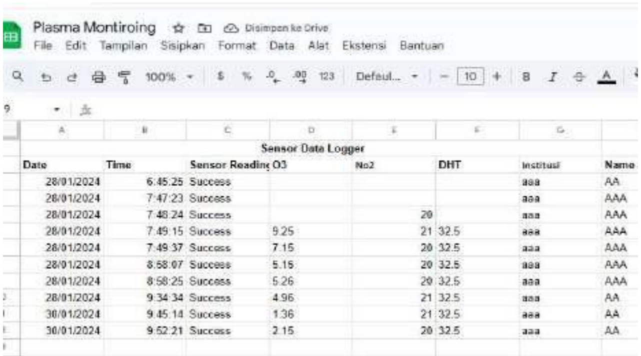
Figure 6. Concept of Used Tools

The non-thermal plasma monitoring system is designed to use the Bluetooth network and the internet as data transmission media, which may be shown and saved in real time. This system incorporates an Arduino Uno microcontroller and an Android application built with MIT App Inventor. The Arduino, which is outfitted with several analog and digital sensor modules, transmits sensor reading data to the Android handset via the Bluetooth HC-06 module. The received data is not only displayed on the Android application screen, but also saved in an internet-based database. As a result, an internet connection is essential for ensuring that data transmission happens smoothly. The usage of the internet network enables the deployment of the control system and the storing of plasma testing activity parameters.

(a) Result Tools Monitoring

(b) LCD12C Display

(c) Software Android Result



Sensor Data Logger

Date	Time	Sensor Reading	O3	No2	DHT	Institusi	Name
28/01/2024	6:45:25	Success				aaa	AA
28/01/2024	7:47:23	Success				aaa	AAA
28/01/2024	7:48:24	Success		20		aaa	AAA
28/01/2024	7:49:15	Success	9.25	21	32.5	aaa	AAA
28/01/2024	7:49:37	Success	7.15	20	32.5	aaa	AAA
28/01/2024	8:58:07	Success	5.15	20	32.5	aaa	AAA
28/01/2024	8:58:25	Success	5.26	20	32.5	aaa	AAA
28/01/2024	9:34:34	Success	4.96	21	32.5	aaa	AA
30/01/2024	9:45:14	Success	1.36	21	32.5	aaa	AA
30/01/2024	9:52:21	Success	2.15	20	32.5	aaa	AA

(d) Database real-time result

Figure 7. Final Result of The Physical Design

Figure 7 shows the final result of the non-thermal plasma monitoring system design consisting of four main components. Figure 7(a) shows the front view of the device casing that contains the microcontroller and sensor circuits, neatly designed to facilitate maintenance and connectivity between components. Figure 7(b) shows the back of the device, specifically the I2C LCD screen that displays gas parameters directly as an indicator that the device is working properly. Furthermore, Figure 7(c) shows the display results of the Android-based software developed using MIT App Inventor. This application displays the parameter data of the monitoring results, user identity, and the agency concerned. Figure 7(d) shows the online database that records all monitoring results in real-time using a cloud-based spreadsheet. The integration of these four components shows that the system has been successfully designed not only to display and store data, but also to record user identities so that each plasma testing activity can be traced thoroughly and accurately.

d. Evaluation Performance Tools

According to [21], the average ozone concentration in the city of Bandung between 06:00 and 07:00 is approximately 10 ppb. This reference value was used as the basis for calibrating the Arduino program, in which the ADC readings from the sensor were compared with the reported standard concentration. After the calibration model was embedded into the program, the next step was to evaluate the measurement accuracy by calculating the Mean Absolute Error (MAE), as shown in Equation (1). Figure 8 presents the validation results, including the graph of sensor performance and the average MAE obtained from eight initial validation experiments conducted during the same time period, namely 06:00–07:00 WIB [24], [25]. Subsequent validation should be conducted using a substantially larger dataset to enhance the reliability and credibility of the findings.

$$MAE = \frac{1}{n}\sum_{t=1}^{n}|A_t - P_t| \tag{1}$$

Where
A_t = Actual Values

P_t = Prediction/ Model Values

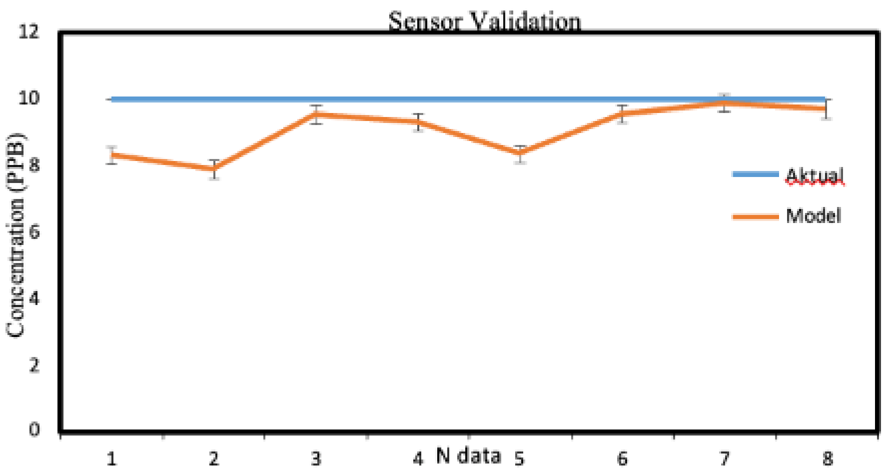


Figure 8. Result Evaluation Performance Test

The average evaluation result using the Mean Absolute Error (MAE) method shows that the sensor exhibits an average deviation of 0.6625 ppm from the actual concentration of 10 ppm across eight measurements. MAE is an appropriate metric for evaluating gas concentration measurements because it directly quantifies the average magnitude of error in the same unit as the observed parameter,

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making it more reliable than percentage-based metrics for concentration data. A lower MAE value indicates a more accurate measurement performance, with values close to zero reflecting minimal deviation between the sensor output and the reference measurement. According to commonly accepted error-evaluation guidelines, MAE values below 1 ppm for low-range gas concentration measurements are considered indicative of good agreement and acceptable sensor performance. Therefore, the MAE result of 0.6625 ppm demonstrates that the sensor provides reasonably accurate and stable readings under the test conditions. However, this assessment represents an initial validation, as the number of observations is still limited. In future research, the dataset should be significantly expanded to improve statistical robustness, increase measurement reliability, and enable a more comprehensive assessment of sensor performance across varying conditions.

4. Conclusion

Based on the results of the analysis and discussion, the objectives of this study were successfully achieved, namely the development of a real-time non-thermal plasma treatment monitoring system for textile applications, integrated with Android-based visualization and a cloud-supported database. The system was designed using an Arduino Uno microcontroller equipped with ozone and NO_2 gas sensors, as well as a temperature sensor, enabling direct data acquisition and display through both Android devices and an I2C LCD interface. The recorded data can also be stored in an online database, providing a more effective, accessible, and well-documented evaluation and control process.

The validation results indicate that the system meets acceptable performance criteria. The evaluation using the MAE method shows an average deviation of 0.6625 ppm from the reference concentration, demonstrating that the system can deliver reasonably accurate measurements for preliminary monitoring purposes. However, this validation represents an initial assessment, and future studies should employ a larger dataset to strengthen statistical reliability and further verify the system's performance. Overall, the developed system is suitable as a monitoring tool for non-thermal plasma processes in textile and applied research settings.

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