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Utilizing Conductive Fabrics in Technical Textiles Using Arduino Uno Microcontroller

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ABSTRACT

In recent years, wearable technology has become an increasingly widespread phenomenon, finding applications in health, sensors, defense, and daily life. It is now possible to create textile materials with conductive properties by incorporating carbon or metals like silver, nickel, and steel into their structure, either in the form of wires, fibers, or micro and nano particles. Electrically conductive yarns with a multifilament core consist of several electrically conducting filaments wrapped around the core. These conductive textile materials offer protection against incendiary discharge and harmful electromagnetic waves, as well as help prevent charge accumulation on devices. In this research, conductive yarns and fabrics based on polypropylene (PP) were utilized, and their conductive and sensing properties were investigated. The electrical behavior of these e-textiles was detected using an Arduino Uno microcontroller. The experimental results indicated that in electro-textile circuits, analog values were recorded and needed to be converted to digital values through an analog-to-digital (AD) converter mechanism. Arduino has a built-in AD converter capable of reading analog voltages ranging from 0V to 5V and converting them into digital values from 0 to 1023. The Arduino microcontroller, integrated with conductive yarns and fabrics, utilized analog inputs to read various voltages in the e-textiles. These analog inputs allowed the microprocessor to monitor the gradual changes in the state of electronic textiles. Specifically, voltages of 2.03V for conductive yarn and 1.85V for conductive fabrics were recorded. Therefore, the developed conductive yarns and fabrics represent a novel application in technical textiles, serving purposes such as smart clothing, heating elements, health sensors, transportation of electrical signals, and protection against electrostatic discharge and electromagnetic interference.

Keywords: Conductive yarn, Electro-textiles, Microcontroller, Arduino Uno, Technical Textiles

1. INTRODUCTION

The growing field of smart textiles could change everyday life, adding an element of interactivity to commonly used items such as clothing, technical textiles and furniture. Smart textiles measure then respond to external stimuli. “Technical textiles” is a buzz word nowadays, it has a wide range of applications, and in some cases it has completely replaced the conventional material. Textile materials, natural or man-made, are predominantly insulators and as such do not promote the flow of electricity through their structure. This inability to move electrical current causes it to remain static on the surface of the materials – sufficient build-up of this can make electro-static discharge more likely. For industrial processes such as the filtration and separation of liquids, gasses, powders and suspensions – especially those that involve highly flammable fossil fuels and solvents – electro-static discharge can present a high risk of ignition. This is where the need for anti-static cloth arises. In recent years, researchers and industrial companies worldwide have been showing increasing interest in conductive textile products and textile-based composite materials [1]. The term smart textile applies to a range of fabrics with functionality beyond the purpose of traditional fabric. They can be defined as materials that sense and respond to external stimuli Smart textiles are materials and structures that sense and react to environmental conditions or stimuli, such as those from mechanical, thermal, chemical, electrical, magnetic, or other sources [2, 3]. Textiles are materials that can react on themselves, unlike ordinary clothes. The expressions of “smart” and “intelligent” textiles or “wearable electronic” textiles are commonly used interchangeably. The term “smart textile” may refer to either a “smart textile material” or a “smart textile system” [3,4]. Smart textiles can be divided into two categories. The first is passive smart textiles, which change properties according to the environment, including hydrophobic, hydrophilic textiles, and shape-memory materials. This is achieved through how the fabric is constructed such as applying additives or coatings [5]. The second is active smart textiles that convert measured parameters to an electrical signal using integrated sensors and actuators. The sensors detect signals from the environment, and the signal is processed locally by an embedded microchip or transmitted to the cloud for analysis on another device [6]. There has been an increased interest in exploring e-textiles to build sensors that are able to read physiological and biometrical data in real-time, with more products appearing on the market. Electronic textiles (e-textiles) are a form of textiles that, integrating technology, can add new functionalities or forms of expression. E-textiles are the prominent applications which incorporate the conductive yarn. Wearable textile sensors may play a fundamental part making instruments for healthcare widely available, allowing better healthcare management [7]. The textile structures which can conduct electricity are called conductive textiles. It may be either made using conductive fibres or by depositing conductive layers onto non-conductive textiles. A conductive fabric can conduct electricity and is made with metal strands woven into the construction of the textile. It can inhibit the static charge generated on fabric, to avoid uncomfortable feelings and electrical shocks also. Conductive fabrics that dissipate static energy and protect from electromagnetic fields alongside other attributes such as thermal regulation, anti-allergy properties and anti-bacterial properties, have been widely used for nearly two decades. However, it was soon realised that fabrics constructed with conductive fibres such as carbon, gold, stainless steel, silver, or copper could offer great potential by facilitating the integration of ‘soft’ networks into fabrics [8]. The application fields and forms of conductive textiles are very wide. Conductive materials can help to avoid charge accumulation on a device or humans, and also protect from incendiary discharge or electromagnetic waves at frequencies that are potential hazards to health. Conductive textiles are also utilized as sheet covers for equipment or to shield a space from electromagnetic fields. They are also used to ensure the closed current circuit needed for Smart or e-textiles [9]. According to Reyhan et al., 2023 report, the most used conductive polymers are Polypyrrole (PPy), Polyaniline (PANI), and Poly(3,4-ethylenedioxythiophene) (PEDOT), and their chemical structures are given in Figure 1a to 1c. In this research work, PP base conductive yarn and fabrics are used and their conductive characteristic and sensing properties were studied. Arduino Uno microcontroller was used to detect the electrical behavior of e-textiles.

1.1 The varieties, characteristics, and uses of conductive fabrics

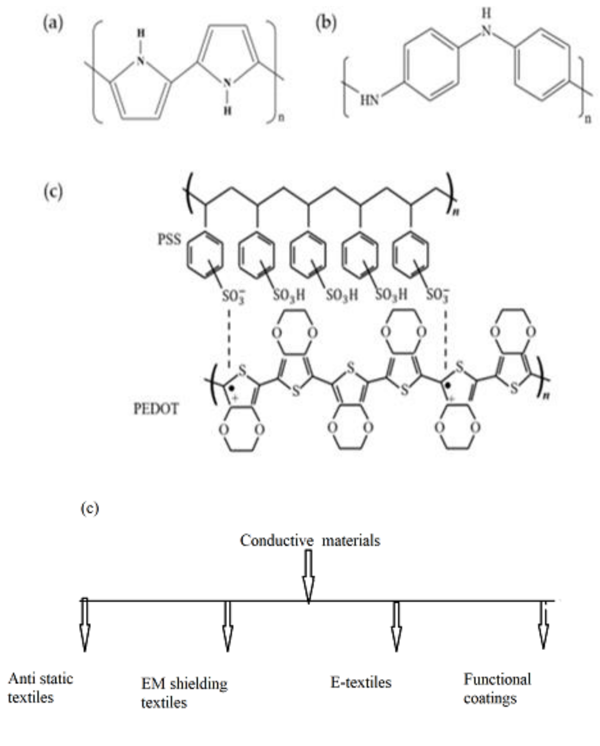


Fig 1. The molecular composition of majority of conductive polymers (a) Polypyrrole (PPy) (b) Polyaniline (PANI) (c)Poly(3,4-ethylenedioxythiophene) (PEDOT) (d) Classification of conductive fabrics

The surface resistivity of textiles can be divided into such groups (Lin and Lou, 2003; CEN/TR 16298: 2011): EMI/RFI shielding materials: less than 104 Ω; conductive textiles: less than 106 Ω; static dissipative materials: from 106 to 1012 Ω; anti-static textiles: from 1010 to 1012 Ω; insulation textiles above 1012 Ω. Generally conductive textiles can be classified as follows in Figure 1d.

Anti-static textiles: Static electricity can the build-up electric charge on the surface of objects. Which can cause many problems for textile materials, manufacturing and handling the product. In the dry textile process, fibres and fabrics can tend to generate electro-static charges from friction. When fibres and fabrics are moving at high speeds on different surfaces, (like: conveyor belts, transport bands, driving cords, etc) causing fibres and yarns to repel each other. These static charges can produce electrical shocks and caused the ignition of flammable substances. Two techniques are known to prevent static electricity in textiles. One is to create a conducting surface and another is to produce a hydrophilic surface. In these ways antistatic textiles are produced to avoid the potential hazards caused by static charge or electricity.

EM shielding: Electromagnetic shielding (EMs) is the process of restricting the diffusion of electromagnetic fields into a space. In this process, an electrically or magnetically conductive barrier is used. Shielding is a common technique for protecting electrical equipment and human beings from the radiating electro-magnetic fields. This barrier can be rigid or flexible. When an EM beam passes through an object, the electro-magnetic beam interacts with molecules of the object and this interaction may take place as absorption, reflection, polarization, refraction, diffraction through the object. EM Shielding textiles materials can be found in the form of woven, knitted, and nonwoven fabric also. The major components of these fabrics are fibres and yarns. To achieve an effective shielding behaviour, these fibres should be electrically conductive. Conductive yarns can be made by blending conductive fibres with conventional staple fibres, twisting conductive or insulator filaments together. For example, conductive metallic yarn (such as: silver, copper, etc.) can be wrapped with insulating textile materials to create hybrid yarns. Which could be integrated into woven or knitted structures. Hybrid yarns or metallic fibre can be integrated into these designs as warp. Electromagnetic shielding effectiveness of the fabric decreased with the increase in fabric openness.

E-textiles: Electrically conductive fibres and yarns have attracted great interest because of their distinguished features including reasonable electrical conductivity, flexibility, electrostatic discharge, and EM interference protection. Conductive textile fibres are the primary component for wearable smart textiles introduced particularly for different applications such as sensors, electromagnetic interference shielding, electrostatic discharge, and data transfer in clothing. Therefore, the demand for electrically conductive fibres and yarns is ever-growing. The development of novel conductive fibres becomes crucial with technological improvement in wearable electronics such as wearable displays, solar cells, actuators, data managing devices, and biomedical sensors. E-textiles play a critical role in selecting the conductivity of smart textile electronics. Textile applications such as lighting, considerable current is necessary and low ohmic fibres are preferred. On another hand, for certain sensing or heating applications lower conductivity would work better. So, it requires fibres exhibiting lower electrical conductivity. E-textiles need flexible and mechanically stable conducting materials to ensure electronic capabilities in apparel.

Functional coatings: For many applications, functional coating is the material interfaces and surfaces that provide beneficial functionality over their intrinsic bulk characteristics. Hence, coatings provide a versatile method of modifying textiles with conductive properties. Subsequently, the textile fabric acts as a supporting structure or carrier material for the conductive finish. Conventional methods such as dip coating or roll coating are typically used to apply bulk coatings in the form of a saturation or lamination that covers the entire “surface” of the textile. However, as will be presented herein, the advent of nano-technology in textile research, the development of novel process techniques, and the advancement of inks and coating formulations affords the opportunity to apply coatings to increasingly finer structures.

Conductive fabrics composed of metallic yarns synthesized via conventional methods are disadvantageous owing to their stiffness, low air permeability, and heaviness [10-12]. The general properties of Conductive Textiles are summarized in Table 1.

Table 1. Characteristics of conductive textiles [10,12]

Properties of conductive textiles				
Physical properties	Tensile properties Breaking strength, [cn]		Electrical properties Electric resistivity, [Ω·m]	
	Yarns from staple Fibers	Yarns from continuous Fibers	Yarns from staple fibers	Yarns from continuous Fibers
Low weight, High strength, Flexibility, Durability, Elasticity, Heat insulation, Water absorbency, Dyeability, Drape, Soft handling, Wash ability, etc	318.8-389.8	382.9-458.5	0.0900-0.1992 For diameter of yarn, [mm] 0.3897-0.8352	0.2365-0.2559 For diameter of yarn, [mm] 0.4256-0.5845

Major application areas of conductive textiles: Electrically conductive textiles make it possible to produce interactive electronic textiles. Conducting yarns are used to manufacture carpets and other items that dissipate static electricity, such as work clothes in highly flammable environments, e.g., in the petrochemistry industry. They can be used for communication, entertainment, health care, safety, homeland security, computation, thermal purposes, protective clothing, wearable electronics and fashion. conductive fabrics that dissipate static energy and protect from electromagnetic fields alongside other attributes such as thermal regulation, anti-allergy properties and anti-bacterial properties, have been widely used for nearly two decades as shown in Figure 2 [13-15].

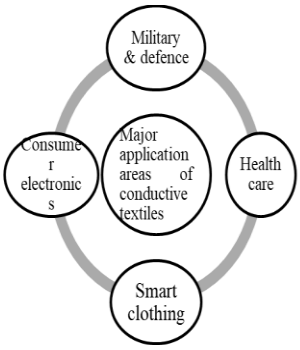


Fig 2. Primary usage areas of conductive fabrics

1.2. How to Manufacture and Work with Electrically Conductive Textiles

There are several methods known to manufacture electrically conductive textiles. The simplest way is to incorporate metal wires or wire meshes into fabrics. Another approach is to use metalized yarns. In staple yarns, it is possible to spin short strands of regular yarns with metal yarns. Electrically conducting yarns may be made of a central metal strand with regular yarn woven around it. It is however also possible to coat a base polymer (such as Polyamide 6 or Polyester) with metal like silver [16]. Methods of producing conductive textiles are summarized as follows:

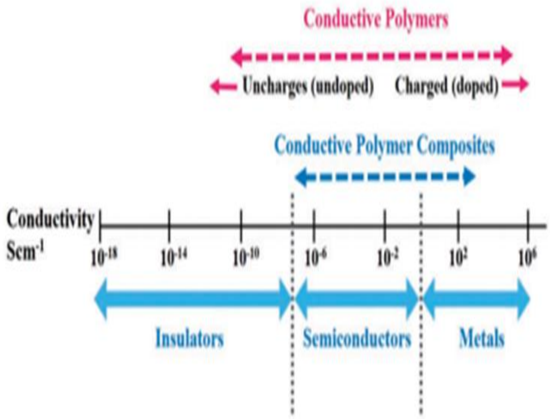
1.Adding carbon or metals in different forms such as wires, fibres or particles.

2.Using inherently conductive polymers.

3.Coating with conductive substances.

When an electric current runs through the resistive material while it's stretched or pushed on, the resistance to the current changes. You can measure this change in value as it's being manipulated, essentially making a force or stretch sensor.

(a)



(b)

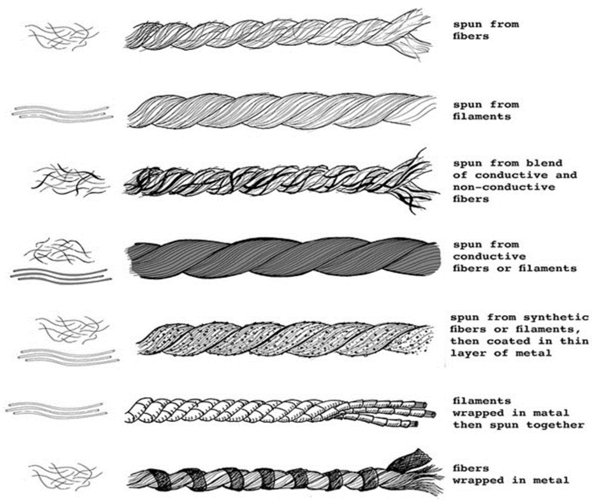


Fig 3a. The spectrum of conductivity exhibited by polymers in comparison to the conductivity of other materials. Fig 3b. Common Manufacturing methods of Conductive Textiles [17,20]

Another approach involves designing a variable resistor, similar to a potentiometer. A resistor ladder provides an uncomplicated way to obtain multiple resistance values. This step guides through the process of creating a resistor ladder with distinct contact points, each yielding different Ohm readings. Similar to a potentiometer, this setup can be integrated into a circuit or used with a microcontroller as needed.

2. MATERIALS AND METHOD

2.1. Materials

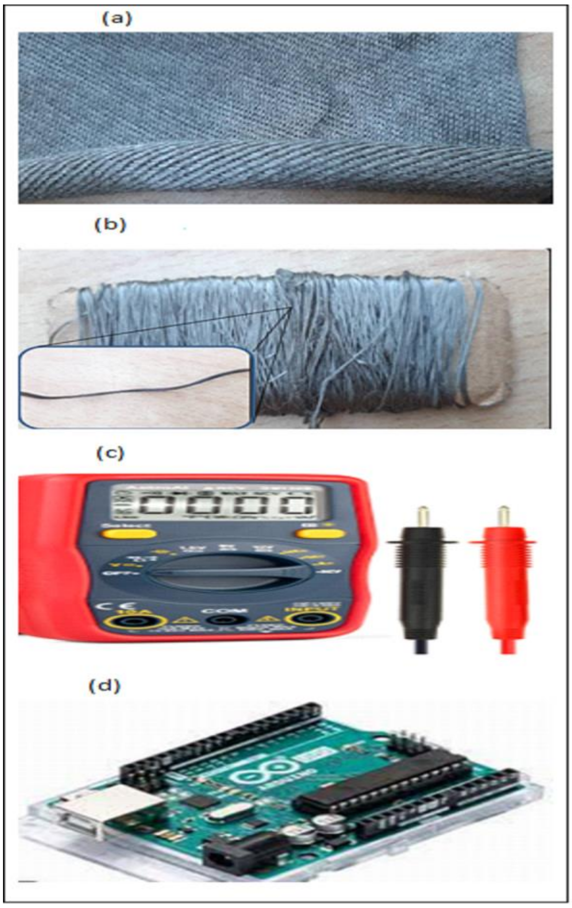


Fig 4a.Conductive textile yarn; Fig 4b. Conductiv knitted fabric; Fig 4c. Conventional voltmeter and Fig 4d. Arduino uno

PP base conductive yarn and fabrics are used and their conductive characteristic and sensing properties were studied as shown in Figure 4a and 4b respectably. Voltmeter and Arduino Uno microcontroller were used to detect their electrical behavior of e-textiles as shown Figure 4c and 4d [17].

2.2. Method

Conductive knitted fabric was manufactured using PP conductive yarns with a special knitted machine. It was fabricated by e bundle drawing processes and manufactured by BEKAE, Belgium. The conductive yarn was converted into textile fabric by knitting. The conductive fabric as shown in Figure 4b was manufactured by a specially designed knitting machine the yarn filaments was formed by multifilament 2/1 ply and 555Tex count. The basic objective of this research work is to integrate textile materials with Arduino UNO microprocessors and computer coding for better and easier control of smart textile materials. The electrical properties obtained by inserting conductive yarns were compared based on their surface resistance and electric-heating properties.

(a)

(b)

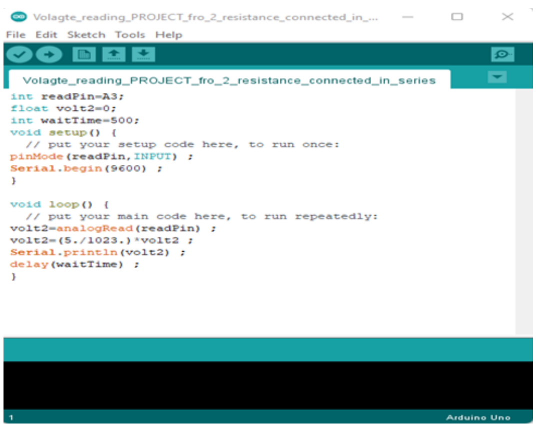


Fig 5a. Process of measuring conductive fabric properties; Fig 5b. Code for reading voltage using Arduino uno

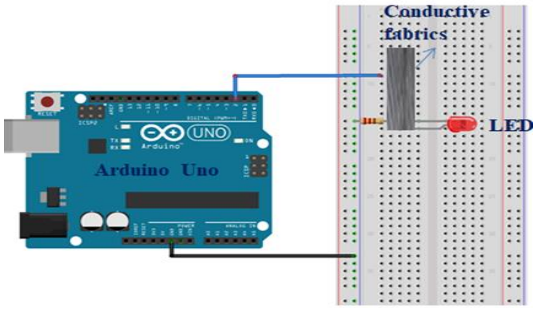
As shown in Figure 5a, the surface resistivity of the conductive textile was measured using milliohm meter based on AATCC 76-1995 via Arduino Uno microprocessor to convert the analog-to-digital values. The final surface resistivity was obtained by averaging ten measurements obtained at different positions of the conductive knitted fabrics. The textile samples measured

3 cm × 10 cm in the test direction. The sample was supported at a distance of 5 cm using two alligator clips, and the initial resistance value was measured. Thereafter, the sample was stretched to observe the change in resistance based on elongation rate. The fabric resistances were tested at 0%, 50% and 100% elongations and the average value of the electrical resistance was calculated. [18]. Arduino microcontroller integrated with conductive yarn and fabrics were supported in an analog input to read various voltages in the e-textile. Analog inputs enable the microprocessor to read the state of electronic textiles that change gradually and were recorded as shown in Figure 5b.

3. RESULTS AND DISCUSSION

The analog-to-digital converter (ADC) turns the analog voltage into a digital value. The function that conductive fabrics (yarns) use to obtain the value of an analog signal is analog Read (pin). This function converts the value of the voltage on an analog input pin and returns a digital value from 0 to 1023, relative to the reference value. For this research work the default reference voltage is 0V and 5 V (for 5 V Arduino boards) When value = 0(0V), the signal is always off. When value = 255 (5V), the signal is always on. As shown in the Figure 6a and 6b below, an LED is connected to pin 2 of the Arduino via PP conductive textile fabric. To change the brightness of the LED connected with the conductive fabric, the program will vary the duty cycle of the pulse-width modulation modulate (PWM) signal output of pin2. The experimental results revealed that when Arduino gets 0 V on the Analog input it gives digital output 0. Arduino gets 5 V on the Analog input it gives digital output 1023 without conductive textile materials. When an Arduino connected with conductive fabric gets 0 V on the Analog input it gives digital output 0. Similarly, when PP conductive yarn connected with Arduino gets 5 V on the Analog input it gives digital output 1023 for 0% stretched knitted conductive fabric. Analog inputs enable the microprocessor to read the state of electronic textiles that change gradually and the maximum value was recorded 2.03V (the digital out pot is 415) for conductive yarn and 1.85V (the digital out pot is 378) for conductive fabrics for 100% stretched knitted fabric respectively. When the stretched conductive fabric was returned back by 50%, the Arduino connected with conductive fabric get 1.02 V on the Analog input and had digital output 209.

(a)



(b)

```
{
    analogWrite(pwm,25);        //setting pwm to 25
    delay(50);        //delay of 50 ms
    analogWrite(pwm,50);
    delay(50);
    analogWrite(pwm,75);
    delay(50);
    analogWrite(pwm,100);
    delay(50);
    analogWrite(pwm,125);
    delay(50);
    analogWrite(pwm,150);
    delay(50);
    analogWrite(pwm,175);
    delay(50);
    analogWrite(pwm,200);
    delay(50);
    analogWrite(pwm,225);
    delay(50);
    analogWrite(pwm,250);
}
```

Fig 6a. Arduino input and output signals of Conductive fabric; Fig 6b. Controlling the Brightness of an LED Code

Similarly, when PP conductive yarn connected with Arduino gets 1.33 V on the Analog input it gives digital output 272.

Table 2. Analog input and digital output reading based on conductive fabric stretched properties

No. Test	0% conductive fabrics stretched			50% conductive fabrics stretched			50% conductive fabrics stretched		
	Analog inputs(V)	Digital output	Recommendation	Analog inputs	Digital output	Recommendation	Analog inputs	Digital output	Recommendation
1	0	0	Maximum value obtained 5 V	0	0	Maximum value obtained 1.02 V	0	0	Maximum value obtained 2.03 V
2	0.488	100		0.41	100		0.5	100	
3	0.98	200		0.99	200		1.01	200	
4	1.47	300		1.03	300		1.52	300	
5	1.95	400		-	400		2.02	400	
6	2.44	500		-	500		-	500	
7	2.93	600		-	600		-	600	
8	3.42	700		-	700		-	700	
9	3.91	800		-	800		-	800	
10	4.39	900		-	900		-	900	
11	5	1023		-	1023		-	1023	

This result shows shown that, for long lengths of conductive knitted fabrics have more resistance than short lengths conductive textile materials which will cause a large voltage drop on the circuit system. Moreover, the analog input and digital output reading of PP base conducting fabrics are significantly affected by the stretch properties of knitted fabrics as shown in Table 2. The effect of yarn length on the strain and displacement measurement on the electrically conductive textiles is shown in Table 2. The conductivity of textile fabrics depends on the length, size, and as well as geometry. The influences of the linear density of the metal used in the conductive yarn and fabrics, stretching properties of the conductive textiles and yarn and fabric structure have a significant effect on conductivity properties (voltage) of the textile materials. The relatively low conductivity of PP fabric can cause a significant voltage drop along the length of the conductive fabrics and thus reduce their performance.

The higher voltage applied for the same resistance generates more current and it produces more energy, which is issued as increases the temperature and results the conductive textile materials would start-to heat.

4. CONCLUSION

The growing demand for incorporating everyday clothing into wearable sensing and display technologies has significantly propelled the field of electronic textiles, commonly known as e-textiles. Recent research has substantiated that conductive textiles are fabrics capable of sensing external conditions or stimuli, responding intelligently to them, and adapting their behavior accordingly. These textiles have found applications in various sectors such as health, sports, automotive, and aerospace.Analog inputs in electronic textiles allow the microprocessor to monitor gradual changes in their state. For instance, recordings indicated voltage readings of 2.03V for conductive yarn and 1.85V for conductive fabrics. Moreover, the electrical properties of the fabric were significantly influenced by factors like fabric length and stretching properties, particularly when the conductive fabrics were produced using knitted fabric fabrication methods. Consequently, the development of these conductive textile materials holds great promise and opens up new application areas in the realm of smart textiles, including smart clothing, heating elements, health sensors, electrical signal transportation, as well as protection against electrostatic discharge and electromagnetic interference.

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