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Review

Fabrication of Multifunctional Tents Using Canvas Fabric

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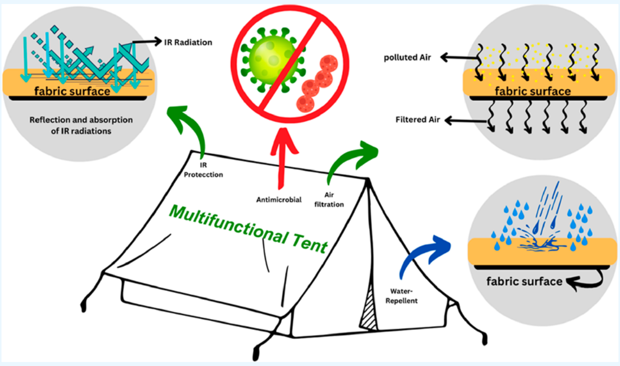

ABSTRACT: Herein, this study was compiled to investigate a suitable solution for the fabrication and development of the multifunctional defense tent from previously reported research. The military always needs to protect their soldiers and equipment from detection. The advancement of infrared detection technology emphasizes the significance of infrared camouflage materials, reducing thermal emissions for various applications. Objects emit infrared radiation detectable by devices, making military targets easily identifiable. Infrared camouflage mitigates detection by lowering an object's infrared radiation, achieved by methods such as reducing surface temperature, which is crucial in designing military tents with infrared (IR) camouflage, considering water repellency and antibacterial features. Water repellency, as well as antimicrobial properties, in army tents is also important as they have to survive in different situations. All these problems should be addressed with the required properties; therefore, the authors try to introduce a new method from which multifunctional tents can be produced through economical, multifunctional, and sustainable materials that have IR protection, water repellency, ultraviolet (UV) protection, air filtration and permeability, and antimicrobial properties. There is still no tent that performs multiple functions at a time, even those functions that do not correlate with each other such as water repellency, IR protection, antimicrobial, and air permeability. So, a multifunctional tent could be the solution to all these problems having all the properties discussed above. In this study based on the literature review, authors concluded a method for the required tent for canvas fabric coated with zinc sulfide (ZnS), graphene oxide (GO), and zinc oxide (ZnO), or these materials should be incorporated in fiber formation because fiber composition has more impact. These multifunctional tents will be very beneficial due to their multifunctions like weather resistance, durability, and long life. These would help the army in their missions by concealing their soldiers and equipment from detection by cameras and providing filtered air inside the tent in case of gases or explosions. The proposed method will help to fulfill the stated and implied needs of customers.

1. INTRODUCTION

In nature, the ability to hide and avoid being noticed can frequently mean the difference between life and death. Camouflage has evolved naturally over thousands of years as a means of survival for both prey and predators.[1,2] This article's objective is to assess canvas materials' infrared (IR) camouflage (seen in Figure 21) abilities of tents in terms of its ability to repel water and have antibacterial and air filtration capabilities. The tent is a type of shelter that has clothing sheets or materials thrown over it and is supported by a rope or pole frame, while smaller tents could be anchored to the ground or be standalone.[1,3] Small tents can be carried easily over long distances using boats or bikes or while backpacking. On the other hand, larger tents are heavier and usually moved using a car or some other vehicle.[4] Setting up these tents usually takes 5 to 15 min, depending on the tent's size and the experience of the person or people assembling it.[5−7] Since ancient times, which have been variously dated between 10,000 and 4,000 years BC, American tribes and Aboriginal Canadians of the Plains Indians have also utilized a type of tent known as a tipi, distinguished for its shape like taper and peak smoke hole.[3,4,8] At least as far back as the early Iron Age, people used tents. Leather tents were employed by the Roman Army, and modern reenactors have used reproductions of these tents with success. Most historical military tents have a straightforward ridge form. The use of hemp or linen canvas for the canopy rather than leather for Romans was a significant technological development. Tents were still primarily used to supply small groups of men in the field with portable shelters. From World.[5,7,9,10]

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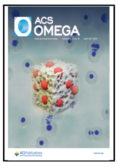

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Figure 1. Several types of tents have been used since ancient times.

Humanitarian catastrophes such as war, earthquakes, and fire frequently include the use of tents. Canvas tents[11−14] are the most popular option in humanitarian catastrophes since they provide temporary protection while allowing for practical breathability.[13] Tents have been a common tool used by armies for an exceptionally long time. Compared to more conventional shelters, the Army preferred the tent for their quick setup and take-down times, as mentioned in Figure 1. The bell tent is a tapered tent design that dates to ca. 600 AD and is one of the varieties of tents covered in this article.[9,15] Berliner is an alpine bivouac for emergencies. Chum is a Siberian version of the Nordic goahte and lavvu as well as the American tipi.[10,16] Wilderness camping tents with standing room at the summit are the Dome, Fly, and Forester.[5,17] Gazebo, the conical-shaped Goahti tent, and Lavvu tent are two similar types of Sámi tents. German Scouts created the Kohte in the early 20th century, a conical tent style inspired by the Sámi people. Loue, Pandal Pavilion, and other nomadic tents are examples of huge tents.[17] The prehistoric to modern inverted V-frame shape is referred to as a ridge tent or "wall tent" in general. Invented in 1856, the Sarrasani Sibley was a tapered tent used by the United States (US) Army both since and during the American Civil War. Sarrasani is a sizable gathering tent that is like it.[17,18] Some North American Indigenous peoples employed a conical tarp tent or tipi. The Inuit utilize a conical shape called a tupiq. North American conical and dome tents known as wigwams and wikiups are frequently bowed Whymper.[5,17] The following military tents[9,19−22] have been created for defense and other purposes: The rapid deployable system (RDS) is one of the quickest and most dependable systems on the market right now.[23] It is also extremely expeditionary and swiftly deployable, does not have an overhead lift, a 300 lb hanging weight is allowed at any one place on the frame, and does not call for additional kits to manage snow, wind, or rain loads. Each tent includes a standard TEMPER vestibule adapter.[23] The military may now access a multipurpose, weatherproof shelter for every operating situation thanks to a modular general purpose tent system (MGPTS), which includes the most recent tension tent design and production technology. With a revolutionary internal arch for support and a clear, unobstructed inner area, MGPTS Type III integrates all the characteristics and advantages of MGPTS Type I.

A stronger, more resilient fielded structure is produced by this exclusive arch system, which directs wind, rain, and snow stresses away from the fabric and directly to the arch (or support system).[24] COMBAT is a two-person, three-season, double-wall, free-standing tent. It features a waterproof floor and flies, a vapor-permeable tent body, and twenty square feet of additional gear storage. Each COMBAT tent is incredibly strong and long-lasting. Over 100,000 COMBAT tents have been deployed so far with zero returns after being evaluated at Aberdeen and in the field. The COMBAT tent has two entrances (entrance/exit ports), and shock-corded poles allow for easy erection and striking without the need for specific tools; 3-pole, free-standing dome tent with a bathtub floor; two-person tent with two doors; twenty square feet of additional storage space in two vestibules; full coverage, reversible, flame-resistant blackout fly for improved environmental protections.[25] The tent combat one person (TCOP) is a tent designed specifically for the U.S. Military. It is built to be dry, sturdy, and quick to set up, and it includes all the essential features needed by field experts.[26] The TCOP is constructed from robust materials that meet or surpass

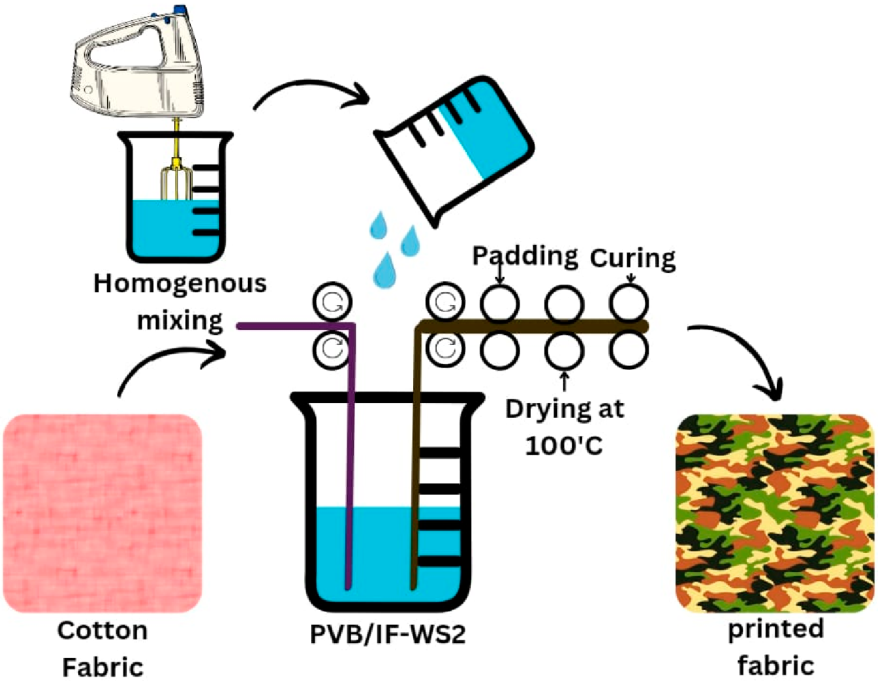


Figure 2. Impregnation of a camouflage pattern using PVB/IF-WS2.

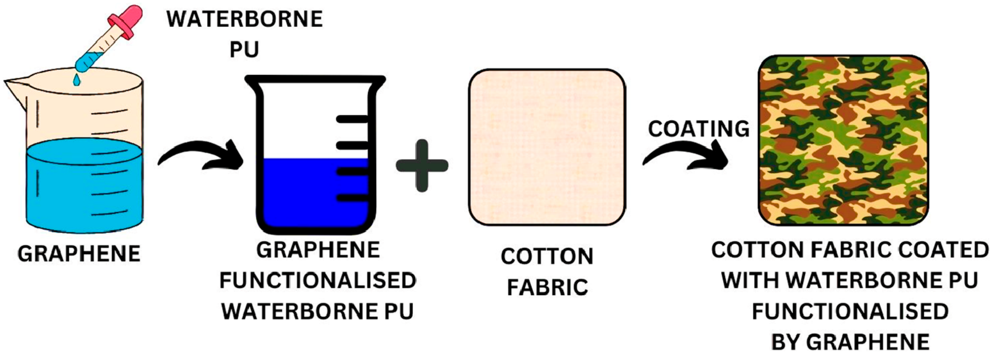


Figure 3. Coating of graphene functionalized PU on cotton fabric.

government requirements, ensuring that they can endure prolonged field use without any doubt. It is superior to the standard Shelter Half in terms of toughness and durability and is an incredibly small and lightweight solo tent; a three-pole, free-standing dome tent with a bathtub floor; two vestibules provide an additional seventeen square feet of storage space; full coverage, reversible, flame-resistant blackout fly for improved environmental protections.[26] The Extreme Cold Weather tent[27−29] has a sixty-four square foot floor area and a 54-in. interior height. It is an all-season tension pole-supported shelter for four soldiers. The tent weighs less than 21.5 lbs and takes up less than 1.6 cubic feet of space in the mission transport configuration. Woodland Camo and Arctic White rainflies are included with each tent, and they offer an additional thirty square feet to the vestibule space, freestanding, with the bathtub floor supporting the pole, a sixty-four square foot main tent body. Additional storage space of thirty square feet is provided by the vestibule. Each extreme cold weather tent (ECWT) includes two Arctic White and Woodland Camo full-coverage blackout flies for maximum environmental protection.[30] Now let us look at the previous work in this field of research.

1.1. VIS and IR Camouflage in Cotton Fabric by Polyvinyl Butyral PVB/IF-WS2. Aleksandra et al. used poly(vinyl butyral), or PVB, and fullerene-like tungsten disulfide nanoparticles, or PVB/IF-WS2, as mentioned in Figure 2 and inserted it into the camouflage pattern.[31,32] Any potential chemical interaction between IF-WS2 and PVB as well as the fabric was ruled out by Fourier-transform infrared (FTIR) analysis. The visible portion of the spectrum has investigated the camouflage behavior of cloth.[32] To investigate the impregnation's ability to blend in throughout the infrared portion of the spectrum, thermal imaging was used.[33] The results obtained indicate that the PVB/IF-WS2 impregnation system enhanced the material's camouflage qualities from MWIR-LWIR, meaning that IF-WS2 improved the fabric's spectrophotometric properties. The advantages of this approach include improvement in visible (VIS) and IR camouflage, providing a camouflage effect that is resistant to washing and wear. The method's drawbacks include its high expense and efficient reduction of reflectance overall.[34,35]

1.2. UV and NIR-Protective Cotton Fabric by Polyurethane. A layer of waterborne Pu functionalized with graphene is applied on cotton fabric, as suggested by Bramhecha et al.[36] as

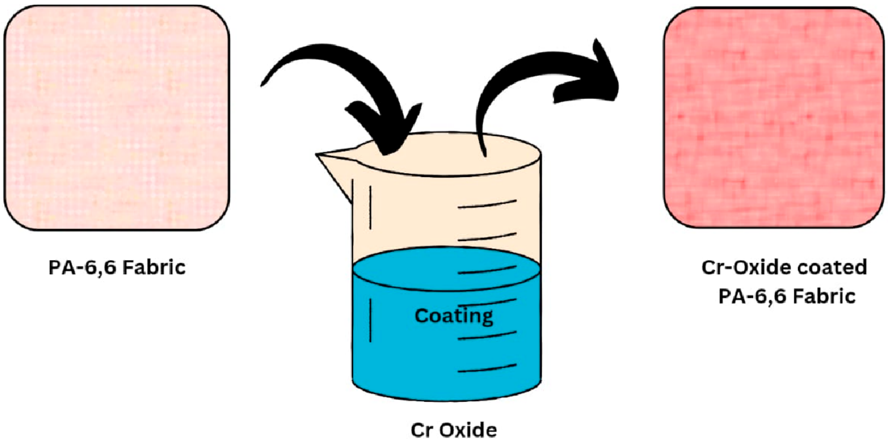


Figure 4. Coating of Cr oxide on PA-6,6 fabric.

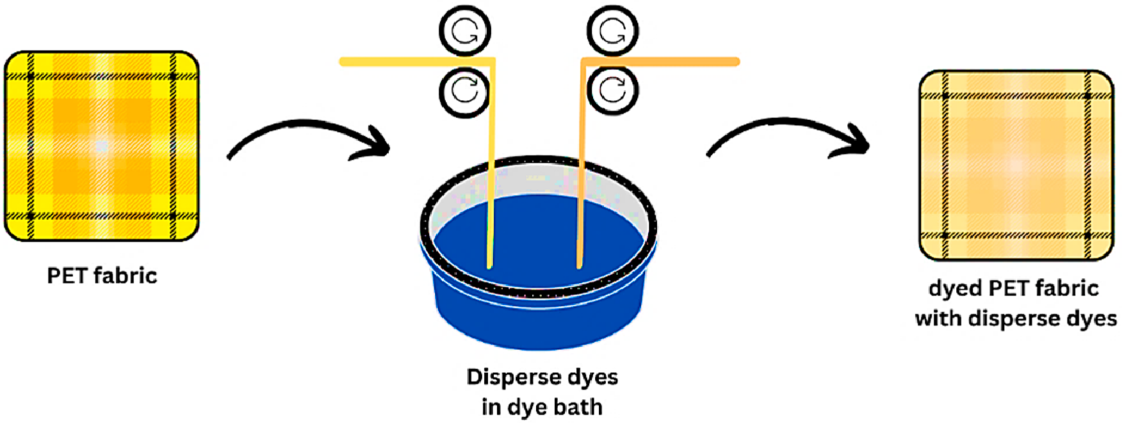


Figure 5. Dyeing of PET fabric using disperse dyes.

mentioned in Figure 3. Based on the results, the treated fabric also showed an impressive ultraviolet protection factor (UPF) of up to 219 and an 88% reduction in near infrared (NIR) radiation exposure.[37,38] The samples that were prepared showed outstanding near-infrared heat insulation, with a remarkable temperature decrease of up to 14 °C, and the sample temperature barely increased.[39] The creation of a flawless nonporous coating over the foundation cotton fabric was verified by scanning electron microscopy (SEM) results. By conducting Fourier-transform infrared spectroscopy (FTIR) and X-ray diffraction (XRD) analysis, the suitability of graphene with the functionalized waterborne Pu (FWPU) matrix was confirmed. This approach has the advantage of enhanced UV and NIR protection, which makes the protective effect robust to washing and abrasion. This technique's drawbacks include decreased fabric softness and a high cost associated with high use concentration.[40,41]

1.3. UV–Visible-IR Protection by Cr Oxide Coating on Textiles.

Using chromium (Cr) oxide and a formulation of polyamide 6,6, Md. Hossain coated Cr oxide on PA-6,6 cloth as mentioned in Figure 4.[42] In this experiment, hyperspectral and digital camera imaging in UV–vis-IR optical signals is used to explore the concepts of chromatic appearance for concealing, detecting, recognizing, and identifying (CDRI) Cr oxide-coated target signatures.[43,44] The findings suggest that when scanning Cr oxide-coated PA-6,6 fabric in the 22,948 μs-Vis-HSI and 10,500 μs-IR-HSI modes, the target signature remained hidden at wavelengths of 400, 500, 600, 700, 2200, and 2500 nm.[44,45] When textile surface Cr oxide is modified and coupled with forest CB, the photon direction may be changed or regulated. The advantages of this method are because of Cr_2O_3's exceptional capacity to absorb or reflect light in the UV, visible, and infrared spectra, and the protective effect is resilient to abrasion and can even endure several washing cycles. Color limitations are a drawback of this approach, which may cause pain during physical exercise or in hot temperatures.[46]

1.4. NIR Camouflage of PET Fabric Using Disperse Dyes.

Hui and team carried out dyeing experiments using a laboratory dyeing machine from Taiwan LABORTEX Co. Ltd. (IR-12P DYER) with a liquid-to-fabric ratio of 50:1.[47] The dye bath had a total volume of 100 mL, and each sample weighed 2 g. They used a dispersion agent called NNO, which also helps with leveling, and added 1 g/L acetic acid to adjust the pH of the dye baths to 5.5. You can refer to the details in Figure 5 for the specific method.[47] Two people participated in the dyeing trials. Following the dyeing, the two samples had their colors measured. The CIE 1976 color coordinates were established by calculating the K/S values based on these reflectance curves. The results indicate that the absorption edge is determined by one of the dyes whose reflectance curves appears at longer wavelengths. Specifically, C.I. Disperse Blue 56 plays a significant role in the NIR green camouflage. This technology has advantages such as efficient NIR camouflage, a reasonably priced solution, and suitability for outdoor or military gear applications on a wide scale. The technique's drawbacks include limited dye options and the possibility of difficulty matching the NIR reflectance profile of particular settings.[47]

1.5. Visible-NIR Camouflage Textile Using CO, PES, and Pigments. Rubežienė et al. employed various formulas, such as CO 65% + PES 35%, Pigments, CO 65% + PES 35%, Reactive + disperse dyes, CO 65% + PES 35%, Vat + disperse dyes, CO 50% + PES 50%, Reactive + disperse dyes, and as mentioned in Figure 6.[48,49] The following were measured and analyzed: color fastness to artificial light, surface color spectrum features in the visible and NIR spectral ranges before and after various pretreatments (cleaning, abrasion, repetitive flexing, and exposure to light), and change in the visible range following the treatments.[48,50] The stability of the concealing qualities of newly created samples of forest camouflage textiles in the visible and near-infrared spectrums was examined.[49,51] Data analysis following certain pretreatments of the textiles under investigation made it possible to compare the printing procedures used and to establish. This approach has the advantages of efficiently absorbing or reflecting radiation in both the visible and near-infrared spectrums. Additionally, CO and PES are reasonably priced materials with good durability. The technique's drawbacks include the thickness and concentration of the pigment in the fabric, which may restrict ventilation and cause discomfort in hot weather or during physical exercise. Concerns regarding the effects of certain pigments on the environment during manufacturing or disposal may arise.[52]

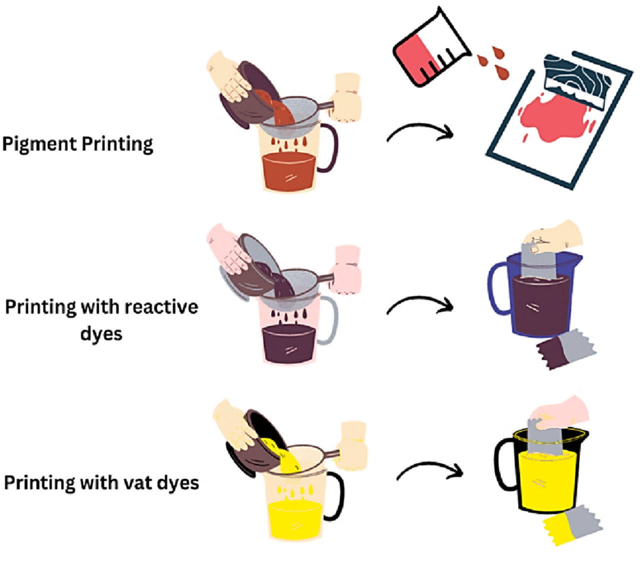


Figure 6. Camouflage print using reactive, VAT dyes and pigment printing.

2. CAMOUFLAGE OF PRINTED FABRICS IN Vis-NIR BY PC BLENDED YARNS

Rubežiene et al. assessed the spectral reflectance for each surface color for all prepared samples (woven textiles made from blended polyester/cotton yarns, pigment printing with various pigments for pertinent color, the sample ratio as mentioned in Figure 7, spanning the VIS and NIR bands.[53,54]) As per the standard LST EN ISO 105-J03:2000, the color difference ΔECMC (Color Measurement Committee) was computed.[54] The fabric samples were first measured for reflectance using a spectrometer to ascertain the degree of camouflage efficiency in the VIS and NIR spectral ranges.[53,55] The results were then compared with those obtained from photo simulation, eye observations made in the field, and night vision goggles used. Photo modeling and spectral analysis were used to develop the approach for evaluating camouflage efficiency in the visible and NIR spectral bands. This method's advantages include complete stealth from human sight and being reasonably priced thermal imaging equipment. The technique's drawbacks include issues with breathability and technical difficulties.[53,55]

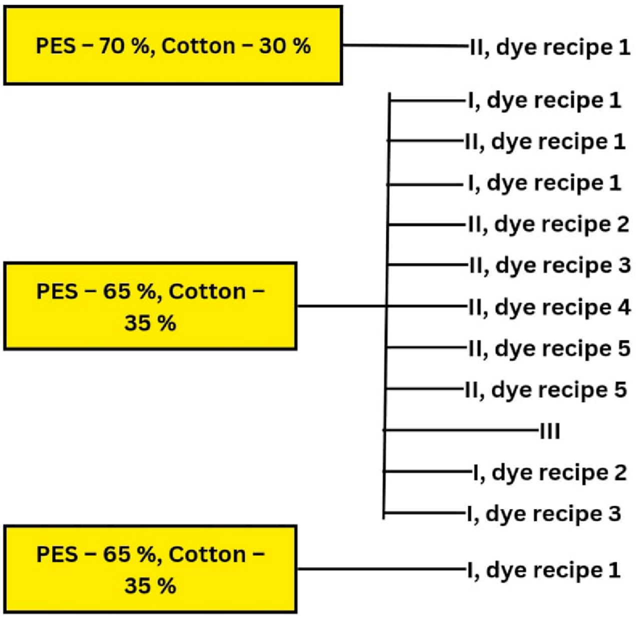


Figure 7. Sample distribution with different colors (I, II, III) and dyes.

3. MULTILAYER FABRIC FOR INFRARED STEALTH AND THERMAL INSULATION BY Al-DOPED ZnO

Xu Rui et al. developed a sandwich structure by hot-pressing carbon nanotube-doped aerogel (CNTAs) onto polyimide (PI) fabric, as shown in Figure 8.[56] They also applied a low-emissivity coating of Al-doped ZnO (ZAO) to the exterior.[56] The inclusion of ZAO results in a surface emissivity of less than 0.5, and the thermal conductivity of the intermediate interlayer aerogels is as low as 0.013 W/(m·K).[57,58] Because of its distinctive structure and superior qualities, we found that the final composite exhibited excellent infrared stealth performance and exceptional insulation capabilities. This suggests that it holds great promise for applications in the fields of infrared stealth and thermal insulation protection industries. Advantages for this method include AZO's potent near-infrared (NIR) absorption and reflection properties, which provide resilience against abrasion. Environmental considerations and long-term stability are the technique's drawbacks.[59]

4. GRAPHENE FABRIC FILM FOR INFRARED CAMOUFLAGE

Cui et al. put a graphene layer over SiO_2 fabric in accordance with specifications for SiO_2 fabric of around 800 cm by 40 cm in diameter for a CVD reaction chamber operating under low-pressure chemical vapor deposition (CVDLPCVD).[60−62] Chemical vapor deposition (CVD)-grown graphene sheets have demonstrated superiority in large-scale homogeneity, controllability of thickness, and excellent crystallinity.[60,61] A substantial freestanding graphene fabric film (FS-GFF) is

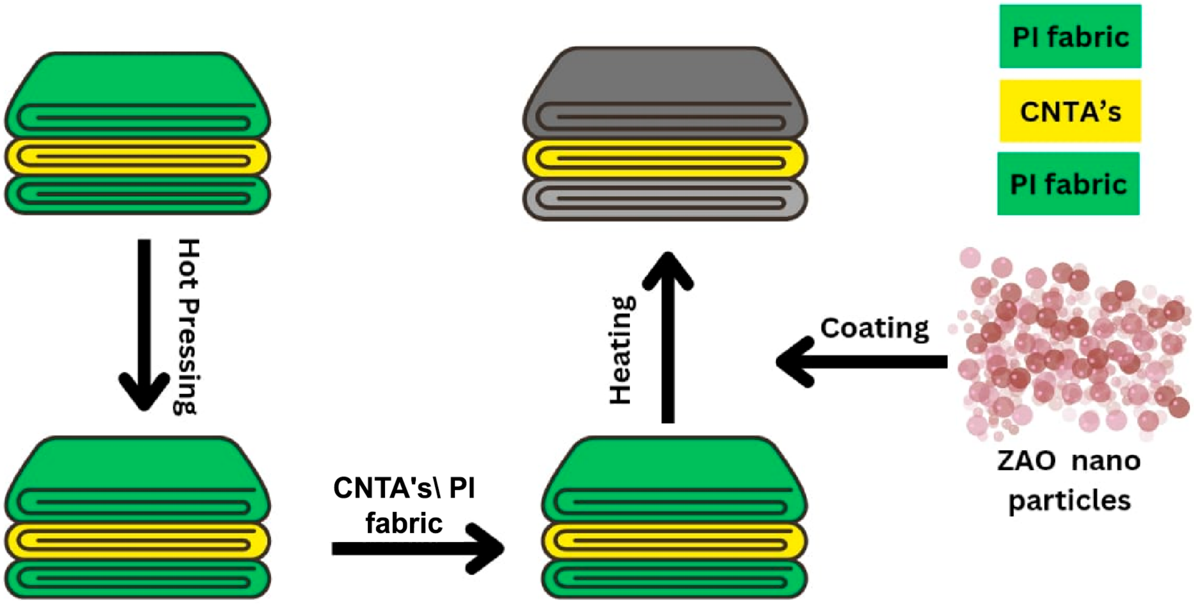


Figure 8. Sandwich structure using CNTAs on polyimide fabric.

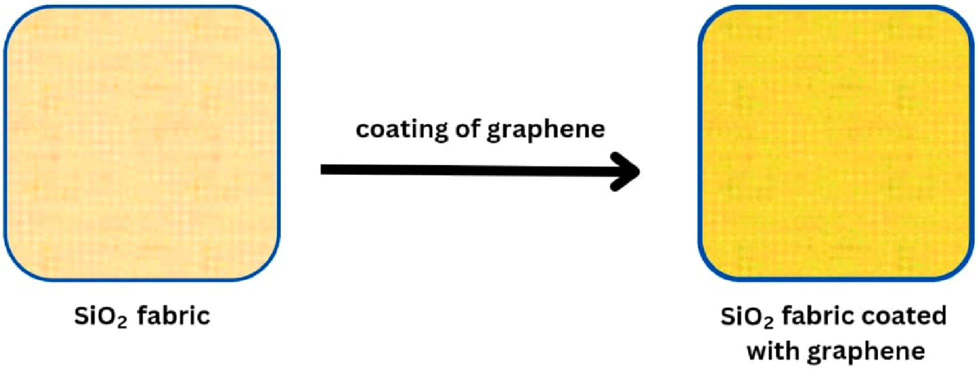


Figure 9. Coating of graphene on the SiO_2 fabric.

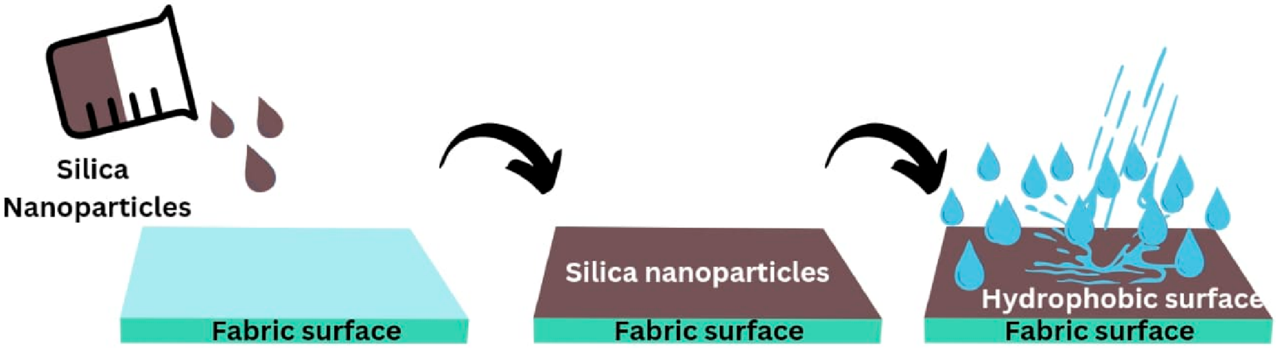


Figure 10. Water absorbing textiles for camouflage using silica nanoparticles.

produced using an etchable fabric substrate, as depicted in Figure 9.[62,63] This study contributes to the progress of research in the field of flexible infrared camouflage textiles and provides a comprehensive understanding of the manufacturing of large-scale freestanding graphene fabric films. This approach has the advantages of effective infrared camouflage, low weight addition, and preservation of the underlying fabric's flexibility. The low breathability and high expense of this technology are its drawbacks.[60,64]

5. OPTICAL PROPERTIES OF WATER ABSORBING TEXTILES FOR CAMOUFLAGE

Örtenberg used hydrophobic chemicals to treat the fabric samples as mentioned in Figure 10 and then compared the outcomes before and after treatment.[1,65] The findings show that, in comparison to their dry condition, hydrated textiles generally exhibit a lower reflectance in the shortwave infrared spectrum because of their high water absorption.[66,67] Nikwax, OrganoTex, water-repellent treatments, and SNPs functionalized with silane compounds were among the hydrophobic agents.[65,67] Improving the hydrophobicity of the cloth surfaces did not increase the water's evaporation time.[66] Though not significantly, the hydrogel and water-repellent Nikwax combination did demonstrate a modest decrease in water, evaporation.[1,68]

6. TEXTILES FOR ANTI-RADAR CAMOUFLAGE FROM POLYESTER

Redlich et al. employ polyester yarns, conductive yarns comprising 5, 15, 20, and 30% steel, together with a portion of carbon fiber and copper wire coated in silver as mentioned in Figure 11 for the sample distribution.[69] The best materials for camouflaging employees and their gear (covers, blankets, and clothes) have the highest absorption factor, the lowest transmission and reflectance coefficients, and both.[70] Out of all the woven textiles created, woven fabric T6 had the best antiradar camouflage characteristics, as verified by laboratory testing. T6 displayed balanced values at both vertical and horizontal polarization.[69,70] The use of properly blended yarns with a portion of metal fibers and the placement of these fibers inside the product's structure are crucial to reaching this level of performance. This method's advantages include being long-lasting and reasonably priced. This technique's disadvantages are its limited effectiveness and long-term stability factor.[69]

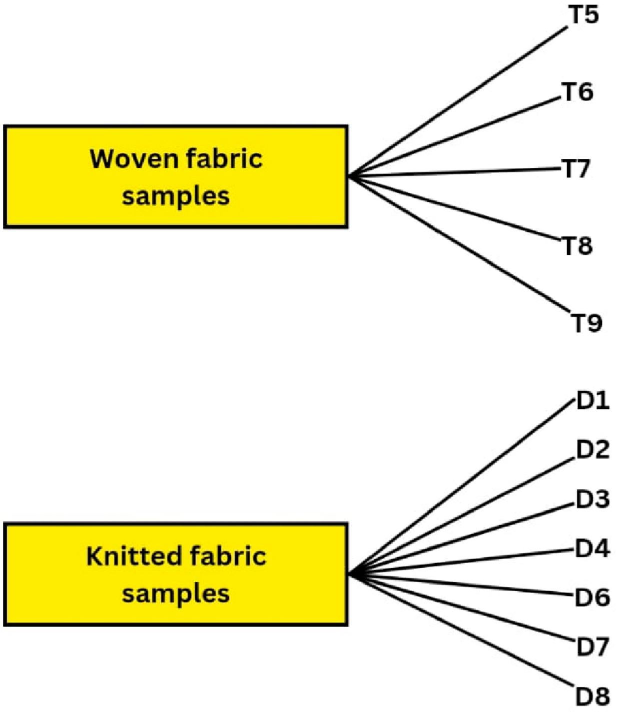


Figure 11. Samples distribution of woven and knitted fabrics.

7. INFRARED REFLECTIVE COATINGS ON COTTON AND SILK FABRICS

On cotton and silk textiles, Gopich and Allaka et al. carry out the dip-coating process and the sol–gel synthesis of titania gel as mentioned in Figure 12.[71,72] The nanoparticles in the deposited coating can function on the surface as a thin, opaque, hydrophobic layer that protects it from outside radiation.[73,74] One material that has all of the qualities to reflect infrared light and keep water from penetrating the substrate surface is titanium. The improved thermal comfort and durability factor are two advantages of this technology. Reduced fabric softness is one of this technique's drawbacks; the cost-benefit analysis is dependent on the intended use and functionality.[75,76]

8. RECYCLED FIBER FOR IR CAMOUFLAGE IN TEXTILES USING POLYCARBONATE

At varying temperatures, Soekoco et al. employ distinct ratios of polycarbonate and poly(acrylic acid).[77] In military camouflage, effectively managing temperature is crucial to minimize the emission of infrared radiation because lower infrared emissions lead to enhanced thermal insulation properties.[77−79] Reducing the thermal signature is essential, and this requires the use of materials with low infrared emissions and excellent thermal insulation properties. Among all heat source temperatures, the fabric with 66.7% polycarbonate and 33.3% polyacrylic had the greatest surface temperature decrease.[79,80] Recycled polycarbonate fibers can be incorporated into knitted fabrics to enhance their mechanical qualities. This technique is appropriate for high-performance textile applications.[77] The bursting strength of a fabric made up of 33.3% polycarbonate and 66.7% polycarbonate was 25% greater than that of a fabric made up of 100% polyacrylic. The material had a greater percentage of recycled polycarbonate. This technology has advantages in that it lessens the environmental impact of plastic trash and offers

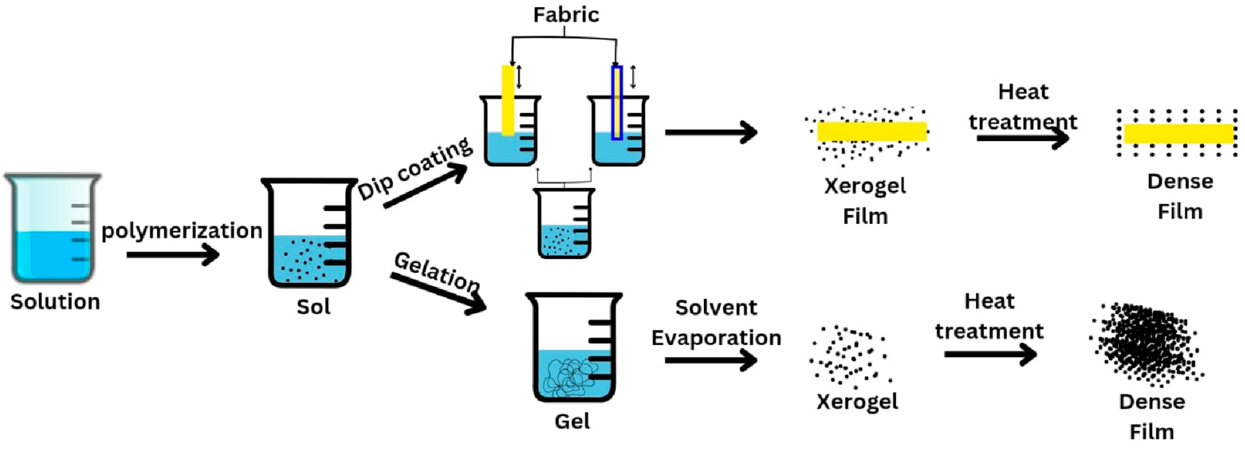


Figure 12. Dip-coating process and sol–gel synthesis of titania gel.

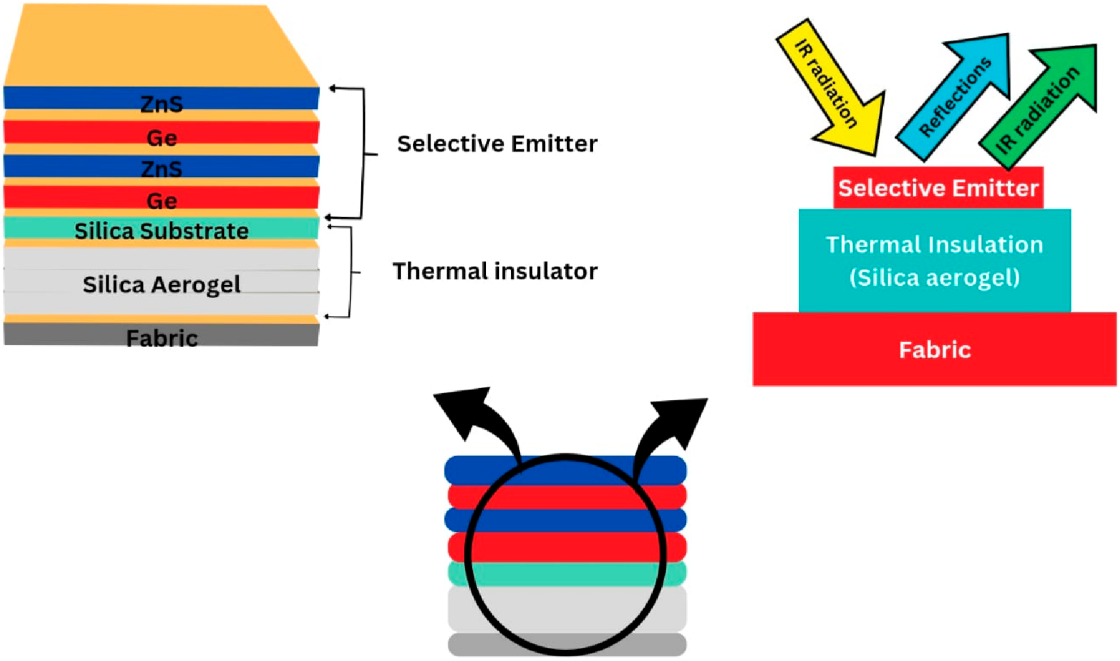


Figure 13. Ge/ZnS multilayer film on a silica substrate.

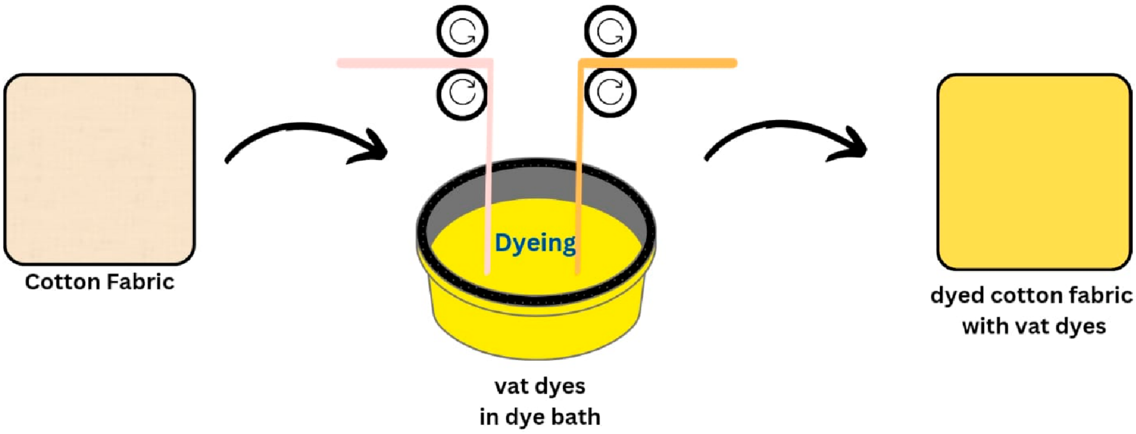


Figure 14. Dyeing of cotton fabrics using vat dyes.

military personnel important stealth capabilities for low-observability applications. One drawback of this process is that it may still cost more to incorporate polycarbonate fibers into fabrics than it would using more conventional techniques.[79]

9. INFRARED CAMOUFLAGE USING Ge/ZnS MULTILAYER FILM ON A SILICA SUBSTRATE

Zhu et al. deposited the Ge/ZnS multilayer film on a silica substrate using E-beam evaporation. They did this at deposition rates of 0.5 nm/s for Ge and 1.5 nm/s for ZnS, as illustrated in Figure 13.[81,82] A high-temperature item (873 K) may successfully have its surface temperature down to 410 K by using silica aerogel as thermal insulation,[83,84,85]. At object temperatures of 873 K (Kelvin) and 623 K, the indoor/outdoor radiation temperatures (with/without Earthshine) are reduced to 310 and 248 K, respectively. Additionally, when using camouflage, the lock-on range with Earthshine is decreased by 76.9% compared to the scenario without camouflage.[82−86] FTIR was used to measure emittance and absorbance by using deuterated triglycine sulfate (DTGS) and mercury cadmium telluride (MCT) detectors. Using an infrared camera with a detection wavelength range of 8−14 μm, the radiation temperature was measured.[85,87,88] The Ge/ZnS multilayer film can withstand 623 K for one hour. This approach has the advantage of effective stealth against cutting-edge targeting technologies. The comparatively high cost of this method and its potential performance degradation due to wear and tear and environmental conditions are its drawbacks.[80,86]

10. NIR CAMOUFLAGE OF COTTON FABRICS USING VAT DYES

Cotton and PET/cotton (65/35) plain cloth were used by Zhang et al., along with a few dyes, to color these materials using various dyes as mentioned in Figure 14.[89−91] Beyond 0.5% of fabric weight, we discovered that Vat Black 27 dyeing concentration significantly affects NIR camouflage.[91,92] Blue 13 is crucial for NIR green camouflage. The cloth dyed in area A exhibits a reflectance like that of a greenish leaf when the concentration of Vat Blue 13 dye is within the range of 1% to 2% of the weight of the fabric. For the same dyeing formula, the

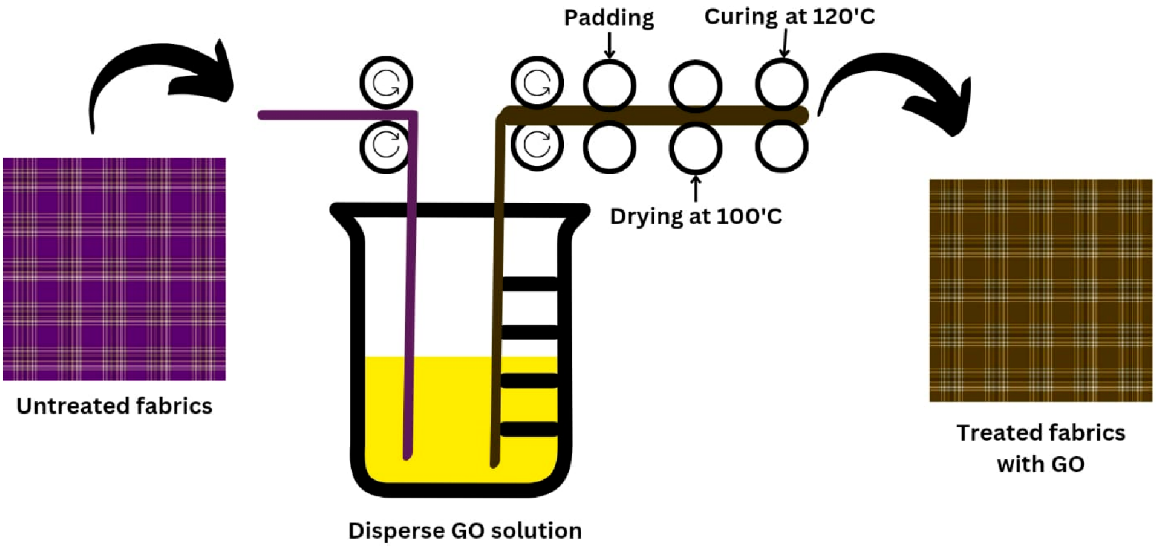
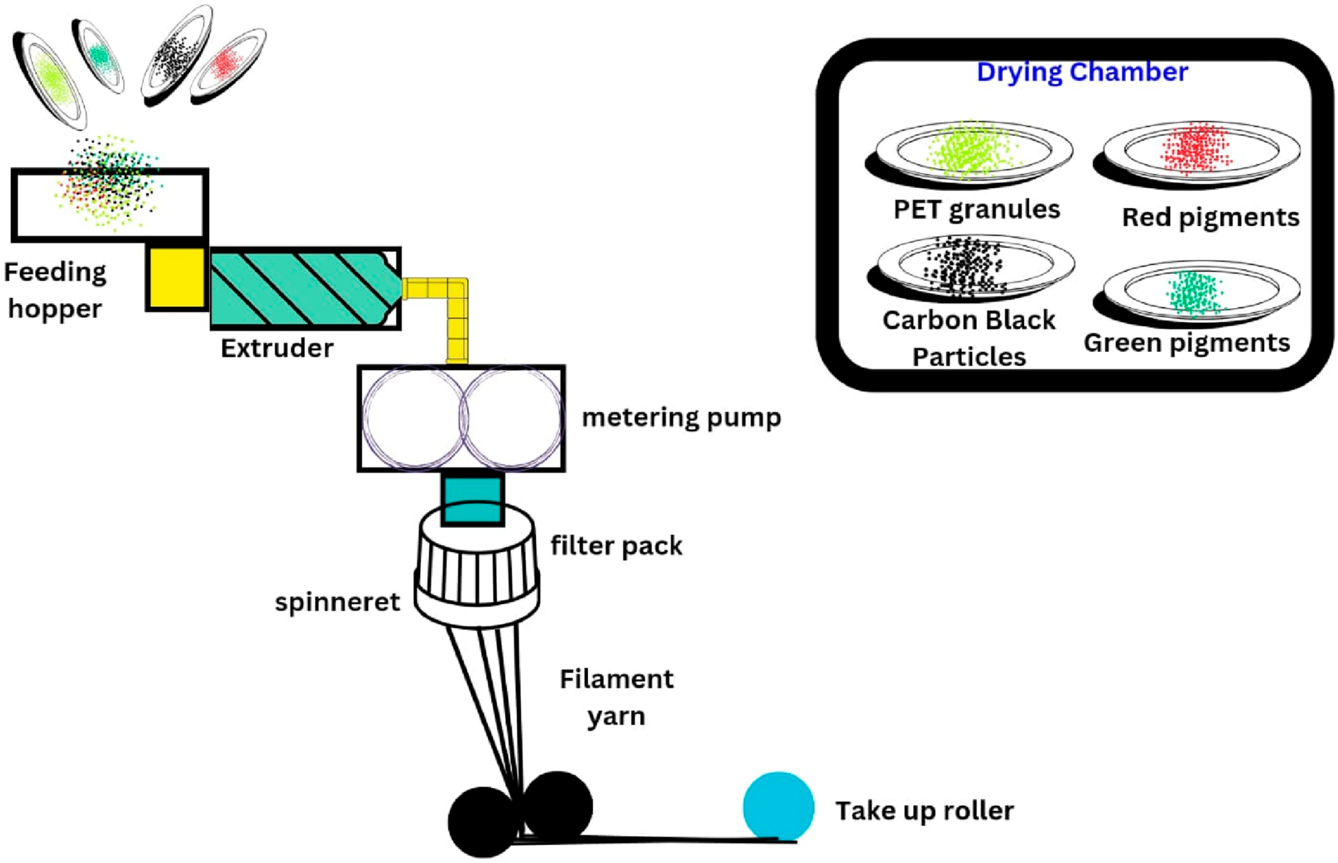


Figure 15. Coating on PC fabric by using GO.



[100], [101], [102].

Figure 16. Filaments created by a melt spinning process by using PET, CB particles, and pigments.

reflectance is slightly influenced by the weave of the fabric. The feature of the dyed cotton fiber mostly determines the NIR camouflage performance for PET/cotton mixed fabrics. Benefits of this method include low-observability applications and useful stealth capabilities for military personnel. The drawbacks of this method are the selected vat dyes may modify the fabric's visible light look while still offering NIR camouflage, therefore jeopardizing its visual camouflage or aesthetic appeal.[91]

11. CAMOUFLAGE PC BLENDED FABRIC COATING BY GO AND rGO

Tariq et al. applied a coating of graphene oxide (GO) and reduced graphene oxide (rGO) to the polyester-cotton blended fabric using a modified Hummer's approach as mentioned in Figure 15.[93−95] According to XRD analyses, the Hummer technique was effectively used to synthesize GO and rGO. GO and rGO were effectively produced using the Hummer process,

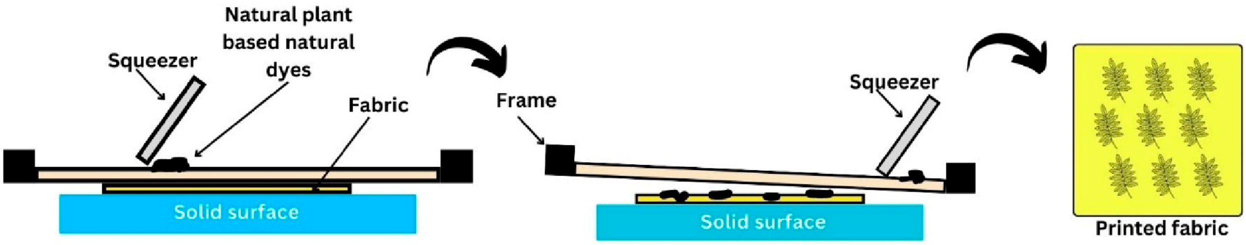


Figure 17. NPND for CB defense protection.

indicating the synthesis of required material, based on XRD measurements.[96,97] Zeta potential values have demonstrated that the material produced forms an effective dispersion in textile applications. A thermal imaging camera operating at 30 °C captured the thermal pictures of the cloth samples treated with GO.[95,98] It is interesting to note that the GO-treated materials significantly improved the body's and the environment's comparable look. Greater GO concentrations helped the cloth samples improve camouflage qualities. Advantages of this method include the special qualities of GO and rGO, which can absorb or reflect both visible and NIR light and perhaps endure abrasion and many washing cycles. The high expense of this approach is a drawback.[93]

12. REFLECTANCE PROPERTIES OF PET YARNS IN THE Vis-NIR REGION

Tavanaie et al. utilized Pigment Green 7 and Pigment Red 177 to create brown-colored mass-dyed PET filament yarns as mentioned in Figure 16.[99,100] The overall visible to near-infrared (Vis-NIR) reflectance of the pure polyethylene terephthalate PET fiber ranges from about 68% to 85%, with the near-infrared (NIR) reflectance specifically falling in the range of 75% to 85%.[101] Carbon black (CB) was introduced into the PET granules in two concentrations, 0.1% and 0.2%. This was done while maintaining a constant concentration of Pigment Green 7 (G = 0.6%) and Pigment Red 177 (R = 0.9%) in two different samples to study the impact of CB powders on the production of brown fiber.[101,102] The results indicated that reducing the concentration of colored pigments by approximately 0.1% while keeping the amount of carbon black constant resulted in a 4% increase in reflectance in the near-infrared (NIR) region for the samples.[102−104] Carbon black not only did not adversely affect the properties of the samples but also contributed to a strong reflection of the brown color in the near-infrared (NIR) range. Positive aspects of this method are that PET is a strong and resilient material that can withstand abrasion and wear and tear; it may be a more affordable option for large-scale manufacture of yarns. The long-term durability of the customized reflectance qualities and their effect on the overall performance of the cloth are the technique's drawbacks.[100−102]

13. CAMOUFLAGED TARGET DETECTION BY SNAPSHOT MULTISPECTRAL IMAGING

Huang et al. have introduced a quick and precise method for detecting camouflaged targets by utilizing a snapshot multispectral camera.[105,106] First, they identified various general-purpose bands used for camouflaged target detection using snapshot multispectral imaging technology and band selection methods. Furthermore, they introduce a method that relies on the constrained energy minimization (CEM) algorithm and an improved OTSU algorithm to dynamically segment the camouflaged target area in multispectral images (MSIs). The CEM detector is employed to obtain the initial detection results.[106−108] The experimental results involving two different targets within four typical urban scenes indicate that our proposed algorithms outperform other methods in camouflaged target detection using just four bands, as opposed to those using all 25 multispectral bands. This has significant practical implications. Furthermore, our method displays superior robustness in experiments conducted with multiple focal length lenses, simulating variations in the imaging distances. One of the technique's advantages is that SMI can record data in the near-infrared (NIR) and mid-infrared (MIR), regions where many concealment tactics fall short. This technique's drawback is that it costs more than more conventional approaches.[105−110]

14. UV−Visible−NIR CAMOUFLAGE FOR CB DEFENSE PROTECTION

Md. Anowar Hossain worked on natural plant-based natural dyes (NPND).[111,112] *Swietenia macrophylla, Mangifera indica, Terminalia arjuna, Corchorus capsularis, Camellia sinensis, Azadirachta indica, Acacia acuminata, Areca catechu*, and *Cinnamomum tamala* underwent a series of processes. They were dried, ground into powder, extracted, encapsulated with polyaziridine, dyed, coated, and printed with leafy designs on cotton fabric, as depicted in Figure 17. These fabric samples were then subjected to testing against woodland camouflage under the reflection analysis of ultraviolet (UV), visible (Vis), and near-infrared (NIR) spectrums. Various photographic and chromatic techniques in visible imaging were also employed for assessment.[113−115] The NPND dyeing process can be substituted with coating or printing to achieve a higher percentage of NPND deposition and a better development of leafy designs on the fabric surface. This approach aims to create a more symmetrical match between defense target objects (camouflage-treated textiles) and the materials used in woodland camouflage. This innovative formulation may serve as a new model for NPND-based camouflage textiles, offering effective concealment for defense applications while using ecofriendly dyes. Additionally, the NPND-mordanting process plays a key role in achieving natural coloration, with NPND as a primary component. This technique has merits that may allow it to be effective against a greater variety of CB detection devices. This technique's drawbacks are its high cost and restricted availability.[111−116]

15. TEXTILES FOR Vis-IR CAMOUFLAGE WITH PHOTOCHROMISM AND TUNABLE EMISSIVITY

Yang et al. fabricated functional materials designed for visible and infrared-compatible camouflage. These materials were developed using conventional textiles as substrates.[117,118] The

Table 1. Advantages and Limitations of Existing Technologies in Smart Camouflage Textiles

Sr#	technology	merits/achievements	demerits/limitations
1	Pigmentation on surfaces and during dyeing	• Low price • Utilized to print and color textiles[125]	• Dyeing synthetic materials is a difficult task.[125] • Does not perceive, respond, or adjust to outside stimuli.
2	Integrated supplements	• Additives settled within the fiber. • Low price[125]	• Change in color of textiles.[124,125] • Does not perceive, respond, or adjust to outside stimuli.
3	Chromic components	• Remarkable color change • Different stimuli to create a color change. • High speed of response for thermochromic materials[124,125]	• Bad wash and light fastness of dyes.[124,125]
4	Fibers and coatings with low emissivity	• Decrease in emissivity of textile. • Woven or knitted into fabric. • High conductivity[125]	• Reflectivity • Increase weight and cost. • Limited adhesion and corrosion resistance • Metallic fibers are potentially damaging to machinery.[125]
5	Phase-shifting substances	• Undoable change in phase • Thermoregulating effects[126]	• Coated microcapsules can be washed away.[125,126]
6	Polymers with shape memory	• Best shape memory at minimum temperatures for alloys. • Can be processed into fibers and films. • Sense and actuate within one material[127]	• Response speed • Lack of extensibility of shape memory alloys in weaving/knitting processes.[126,127] • Shape memory effects decreased when mixed with other polymers before fiber extrusion.
7	Surface modification	• Cost-effectiveness	• Limited compatibility with processes [130]
8	Electrospinning	• Good surface area, fine structured nanofibers	• require optimization to achieve consistent and reproducible results [131]
9	Situ synthesis of metallic nanoparticles	• Good antibacterial resistance	• Limitations of time, cost, or resources [132]
10	Characterization techniques	• High profile antibacterial activity	• Slow-release behavior of aloe vera (AV)[133]
11	Absorption of UV radiation	• Reproducibility and UV protection factor	• Not account for the diverse range of fabrics and garment designs[134]
12	Self-synthesized AgSD on PAN nanofibers	• Better structural and antibacterial properties	• Limited evaluation of long-term stability[135]
13	Electrospun nanofiber mats loaded with silver sulfadiazine (AgSD) in zein	• Effective antibacterial efficacy and excellent release properties	• Limited long-term stability assessment[136]
14	Chemical treatments or fabric engineering	• Holistic protection strategy against harmful UV rays	• Limited information on long-term durability[137]

ability to adaptively change colors for visible camouflage in textiles is accomplished by harnessing the photochromic isomerization of the chromogen in the coating. There are also several alternative methods for achieving dynamic color changes in the visible spectrum, including ionochromism, thermochromism, and electrochromic[119−121] By modifying the structure of polyurethane and adjusting the chromogen content within the coating, it is possible to accurately regulate the infrared emissivity of coated textiles, which typically falls within the range of 0.77 to 0.94. However, a limitation is that it is challenging to further decrease the infrared emissivity of these coated textiles to lower levels.[122,123] A potential solution would be to dope the coating with metal powder, but this, in turn, would affect the visible camouflage of the coating, thus destroying the compatibility of the multispectral camouflage. The technique exhibits potential for concealment in advanced detectors. The drawback of this method is the difficult technical obstacle of developing materials with washability, durability, and variable emissivity qualities.[121−123]

16. SMART TEXTILES FOR VISIBLE AND IR CAMOUFLAGE APPLICATION

Degenstein et al. aimed to elucidate the technologies that can be synergistically combined, including surface coloring and pigmentation,[124,125] These technologies encompass embedded additives, chromic materials, low emissivity coatings, phase change materials, shape-memory materials, as well as various thermal and mechanical actuation strategies (see Table 1).[126−128] Combining these technologies has the potential to address some of the limitations associated with infrared (IR) camouflage properties. The advantages and limitations of these technologies are demonstrated in Table 1, providing a clear overview of their capabilities and constraints.[124,128,129]

17. TEXTILES FOR VISIBLE AND SELF-ADAPTIVE INFRARED DUAL CAMOUFLAGE

Liu et al. treated a commercially available nanoporous PE (polyethylene) nonwoven textile with air plasma at a power level of 10.5 W for 3 min.[138,139] The treatment process involved three cycles to make the polyethylene (PE) material completely hydrophilic. After achieving hydrophilicity, the hydrophilic PE was placed in a physical vapor deposition chamber, where a layer of gold (Au) approximately 285 nm thick was deposited to enhance its infrared (IR) reflectivity. Following this, the Au-coated PE textile was immersed in a Li-Br (lithium bromide) solution. The resulting smart textile comprises a nanoporous polyethylene (PE) nonwoven textile with aqueous LiBr solutions confined within nanocavities, and it features a thin layer of Au as a low-emission surface modification on one side of the nonwoven PE textile.[140,141] In the moisture-assisted photoengineered textile, the polyethylene (PE) and ions are transparent to infrared (IR), whereas the water domain exhibits a high capacity for absorbing IR radiation.[142,143] Inspired by chameleons and cephalopods, we have created a smart textile with a unique structure that offers a range of remarkable features. First, the textile can automatically and passively adjust its

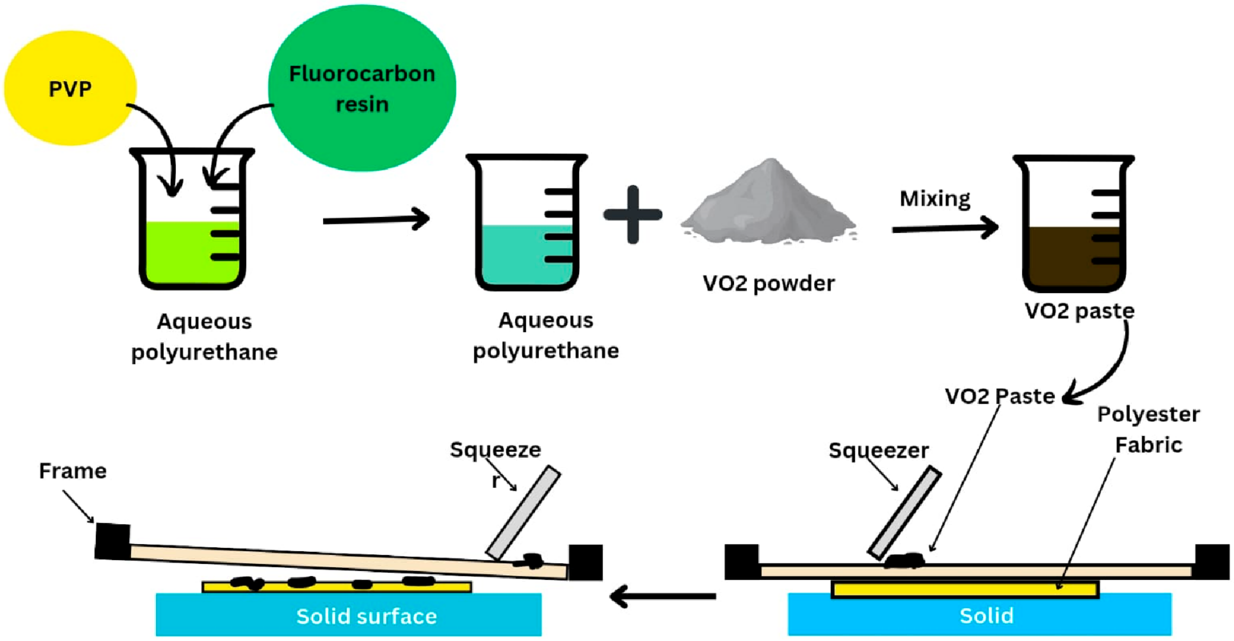


Figure 18. Coating of VO_2 on a polyester fabric surface by screen printing.

thermal emissivity in reaction with temperature changes in the environment. Second, this textile achieves an impressive range of infrared (IR) manipulation, reaching 0.53 with temperature changes of 42 °C. This performance surpasses existing passive IR regulation methods and is comparable with the best approaches available. This strategy has advantages in that it addresses both optical and thermal detection, offering a more comprehensive concealment against a broader spectrum of sensors and observation techniques. The drawbacks of using this method are that it is a difficult technical task to develop self-adaptive materials with strong visible and infrared camouflage capabilities. The challenge is still ensuring long-term efficacy, washability, and durability.[140−143]

18. INFRARED CAMOUFLAGE PROPERTIES OF VANADIUM DIOXIDE NANORODS

Hao et al. applied a coating of VO_2 on the surface of a polyester fabric. To prepare the coatings for infrared stealth, they utilized three commonly used resins: aqueous polyurethane (PU), PVP, and fluorocarbon as mentioned in Figure 18.[144,145] One significant advantage of the three resins is that they are all considered infrared-transparent resins. These resins do not interfere with the infrared properties of the coatings being prepared, and they effectively disperse the sample powders within the three resins.[144−147] The VO_2 nanorods were synthesized by using a one-step hydrothermal method, with V_2O_5 and $H_2C_2O_4$ as the raw materials. The most effective mole ratio between $C_2H_2O_4$ and V_2O_5 was found to be 2:1.[147] Three different polymers were employed to create the VO_2 ink, which was then applied to print the coating onto the surface of the polyester base cloth. Among these polymers, the fluorocarbon resin was found to be the most effective dispersant. The VO_2 coating, when applied to a glass substrate, demonstrated excellent thermochromic properties. It exhibited a significant change in infrared transmittance, surpassing 20% at 1.5 μm, while maintaining a visible transmittance of over 50%. One advantage of this approach is that it may make them extremely reflective in the near-infrared range, which would effectively shield the wearer from thermal imaging equipment. One of this technique's drawbacks is its cost.[146−149]

19. CAMOUFLAGE FABRIC - FABRIC FOR TODAY'S COMPETITIVE ERA

Lal Regar et al. evaluated the effectiveness of camouflage patterns on the fabric using methods such as the probability of detection (POD) and pairwise comparison techniques.[150,151,152] Camouflage fabrics are especially well-suited for use in technical and protective purposes. In recent years, researchers have focused on advancing the development of camouflage fabrics to enhance security measures for military personnel and for activities aimed at concealing facts and deceiving adversaries.[152−154] Extensive research and development efforts have been dedicated to innovating the production of these fabrics, to deliver top-tier performance and dependability.[151−155]

20. RESEARCH PROGRESS ON INFRARED STEALTH FABRIC

Zhou et al. employed coating, dipping, and scraping techniques to assess the infrared emissivity of three pigments: Bi_2O_3, Sb_2O_3, and NiO. The resulting infrared stealth fabric has proven to be efficient in decreasing the radiation emitted from the target surface. It has a wide range of potential applications, including use in military tents, camouflage materials, military uniforms, and various other fields.[156] Currently, the most comprehensive research and practical applications involve the integration of coating materials with fabrics. The primary objectives of this research are to lower the infrared emissivity of fabric surfaces and manage the fabric's surface temperature. The findings indicate that the infrared emissivity of the three pigments—Bi_2O_3, Sb_2O_3, and NiO—is relatively low, measuring below 0.8, making them suitable for use in infrared stealth coatings.[156]

21. DUAL-WORKING MODULAR INFRARED STEALTH FABRIC

Gu et al. developed a dual-functioning module for an infrared (IR) stealth fabric. This module consists of an electroless silver-

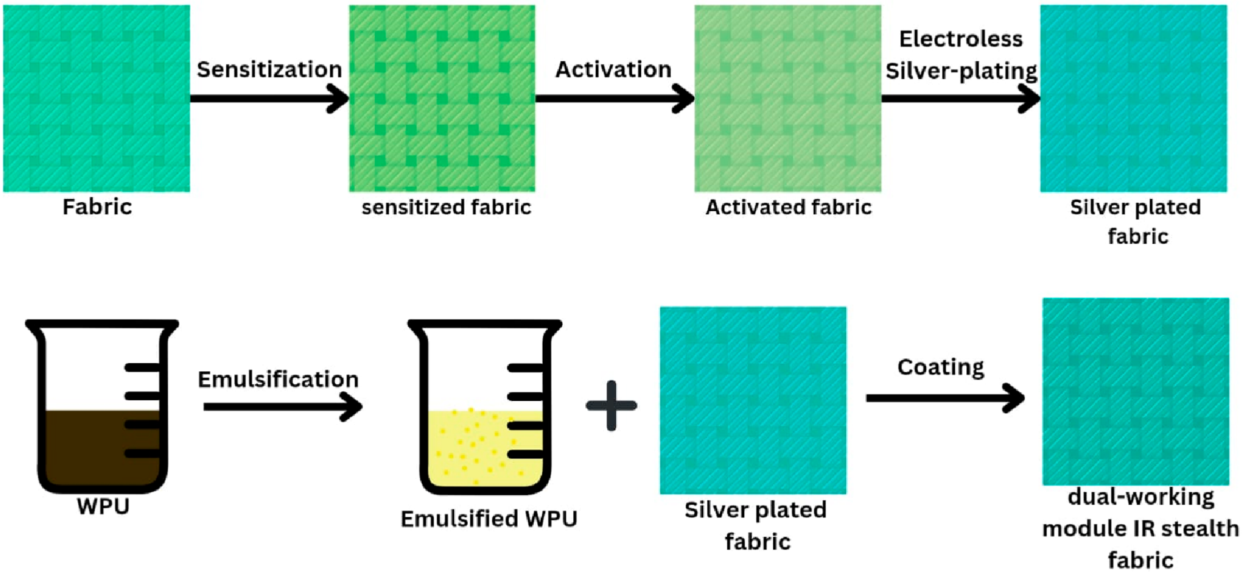


Figure 19. Dual-working modular infrared stealth fabric.

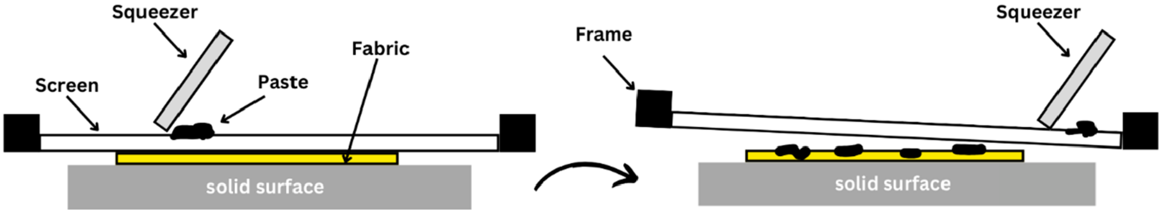


Figure 20. Pigment printing was done using TiO_2 nanoparticles on the PC fabric.

plated fabric component and a heat-absorbing component derived from a phase change material (PCM) coating as mentioned in Figure 19.[157] The objective of electroless silver plating is to decrease the IR emissivity to 0.692 (1−22 μm), 0.687 (8−14 μm), and 0.655 (3−5 μm). Additionally, the PCM coating offers a phase change latent heat of 128.5 J/g, further reducing the temperature. Temperature measurements reveal that the PCM coating can generate a maximum actual temperature difference of 21.6 °C when compared to the untreated fabric on a 65 °C hot plate, and it can maintain the surface temperature below 38 °C for 300 s.[157−159] Infrared (IR) camera images demonstrate that the IR stealth fabric, as prepared, can effectively conceal or disrupt the IR heat signature of the target in comparison to untreated fabric.[158,159] We have successfully created a dual-functioning module for an infrared (IR) stealth fabric that operates by controlling both temperature and emissivity.[157,159] The IR stealth fabric exhibits a low IR emissivity, measuring 0.692 (1−22 μm), 0.687 (8−14 μm), and 0.655 (3−5 μm), thanks to its metalized surface. In terms of temperature regulation, it incorporates a high latent heat phase change coating with a value of 128.5 J/g. When the fabric with this coating is placed on a hot plate at 65 °C, it can achieve a maximum actual temperature difference of 21.6 °C.[157]

22. INFRARED CAMOUFLAGE BASED ON LAYERED MEDIA

Ji et al. determine the optical properties by the transfer matrix method.[160,161] Through the localized alteration of the coating film's thickness, the fabric showcases spatial adjustability and continuity in thermal emission. This results in a gradual transition in emissive power, which is effectively employed to achieve thermal camouflage functionality.[160−163] Furthermore, by employing thickness-engineered multilayer films, additional capabilities such as thermal illusion and thermal coding are demonstrated. These multilayer films with selective emission properties offer a novel approach for use in applications related to infrared camouflage, thermal coding, and thermal illusion.[161,163] Achieving perfect camouflage is feasible through the implementation of a calculated thickness distribution that is continuous and does not require further discretization or approximation. With this approach, various solutions of film thickness can be applied for a given heat source, allowing for flexibility in practical implementation depending on the specific requirements. This approach has the advantage of effective near-infrared camouflage. To get the best NIR camouflage performance, it is important to control the layered media's thickness, composition, and interface qualities.[161,162]

23. NANOPARTICLES ON CAMOUFLAGE PROPERTIES OF COTTON/POLYESTER FABRICS

Jafari et al. printed the samples using a conventional pigment printing method, which involved using a stock paste of synthetic thickeners.[164,165] A vinylacrylic binder was incorporated into the composition of the stock paste. The printing process for all samples was carried out using a flat screen as mentioned in Figure 20.[164] The treated fabrics were both dried and cured simultaneously in a laboratory stenter at a temperature of 160 °C for 3 min. The printing formulations, which included colored pigments, were adjusted to mimic the UV−vis-NIR reflectance characteristics of a dark brown shade in the woodland

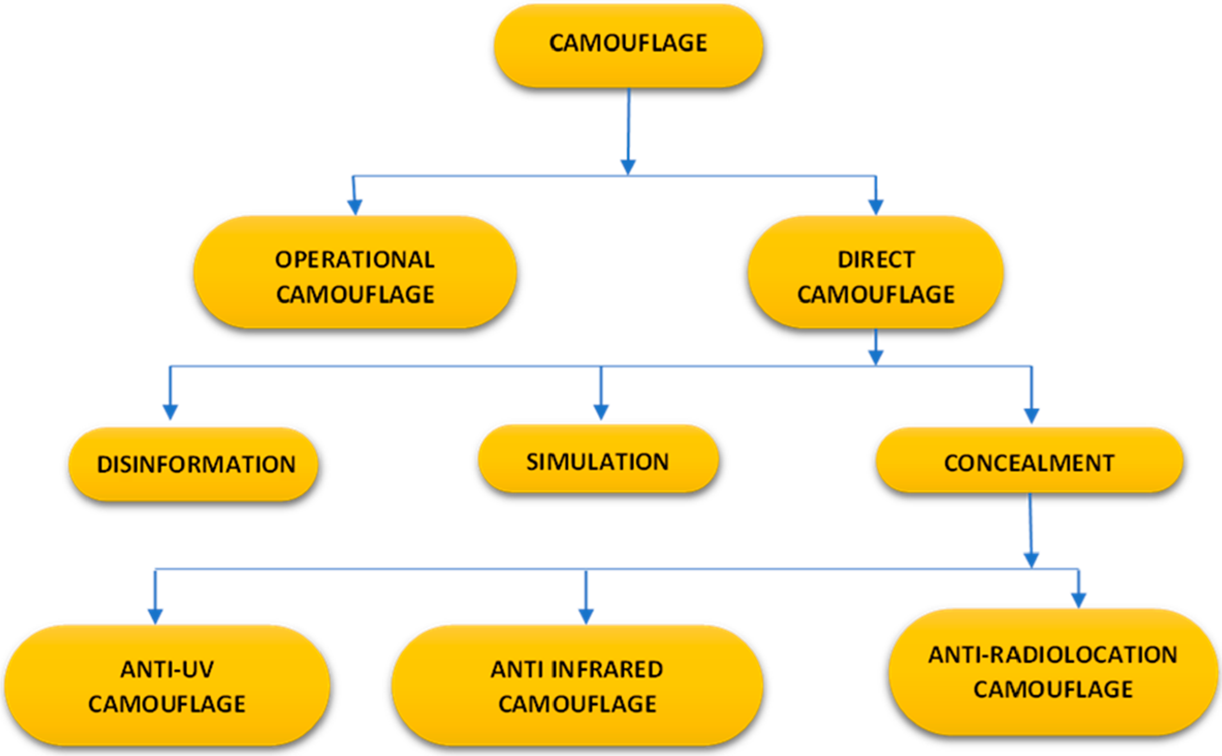


Figure 21. Types of camouflage.

region.[166−168] In conclusion, the addition of ZnO and TiO_2 nanoparticles at a load of 0.25−1 g/kg led to a noticeable reduction in infrared (IR) reflection, particularly at lower nanoparticle concentrations. However, higher concentrations of nanoparticles showed the opposite effect, resulting in an improvement in the IR reflection. The approach has advantages in that it can potentially provide efficient camouflage against a larger range of detection methods, such as thermal imaging equipment and the human eye, but it also has disadvantages in that it is costly.[160,164−169]

24. COMPOSITE MATERIAL FOR INFRARED CAMOUFLAGE

Zhao et al. use all these techniques to prepare composite material for infrared camouflage, following described methods.[170,171] The development process included the following steps: Preparation of Phase Change Microcapsules, Dip Rolling, Coating Method, and Infrared Camouflage Textile and Characterizations and Measurements. The temperature-regulating textile materials with phase change microcapsules were created using the coating method.[172,173] When the content of phase change microcapsules is 27% and the coating thickness is 1.5 mm, the performance of the sample is the best.[173] The results obtained from the infrared thermogram and infrared emissivity test indicate that the double-layer coating sample exhibits effective infrared camouflage when the content of phase change microcapsules in the bottom layer is 27% and the content of flake copper powder in the surface layer is 20%.[172] The material has an infrared emissivity of 0.656 in the 2−22 μm band. When applied to the surface of the human body, it can lower the temperature by 6.8 °C and effectively diminish infrared radiation.[170]

25. CAMOUFLAGE FOR PROTECTION DURING SPECIAL OPERATIONS

Bartczak et al. explain the different types of camouflage as mentioned in Figure 21.[174] The world's leading military forces have access to an extensive array of camouflage technologies designed to operate across a broad spectrum of electromagnetic radiation, spanning from ultraviolet (UV) to microwave frequencies.[172,174] The arsenal of camouflage technologies available to these military forces includes deformable camouflage paints, camouflage covers, radar radiation-absorbing materials (RAM), antithermal camouflage devices, and active camouflage kits. Historically, the scope of camouflage for our armed forces had primarily been limited to the visible spectrum, which did not align with the requirements of modern warfare. However, in the 1990s, research efforts resulted in models for concealing tanks, trucks, and antiradar paints.[175] It is projected that the newly developed material or set of materials will undergo upgrading processes to meet the final product specifications. Potential finishing techniques may include coloring, as well as additional finishes such as water-resistant, hydrophobic, oleophobic, etc.[176]

26. FUTURE DIRECTIONS

The development of a comprehensive tent, integrating features such as air filtration, water repellency, IR camouflage, and antimicrobial properties, remains a challenge. Although there have been significant advancements in individual tent technologies such as IR camouflage and antimicrobial coatings, the development of a tent that combines all these functionalities seamlessly is still lacking. Most current research has tended to focus on specific features and overlooks the compatibility and synergistic effects of various functions.

A comprehensive strategy to meet the essential requirements of outdoor enthusiasts and emergency response scenarios is lacking in the current tent technologies. to provide excellent air filtration, water repellency, IR camouflage, and antimicrobial qualities, a multifunctional tent that integrates modern coating technologies, nanoparticle integration, and layered media techniques is urgently needed.

Graphene oxide, ZnS, and Ge can be added to the fabric to increase its IR protection. We can accomplish high heat reduction and IR radiation protection by employing graphene oxide. The IR camouflage qualities are incorporated into the fabric by using a combination of coating processes and the pad curing procedure. We can coat various fabrics (made of synthetic fibers), but since we need to consider all of the other qualities we want in this tent, we must use natural fibers. Cotton is the most common natural fiber, and using canvas would be preferable because it has a unique property that reduces the amount of infrared radiation that can pass through the fabric. GO is used by us as nanoparticles because of it. We can apply various water repellents (hydrophobic compounds) to the fabric to enhance its water-repellent qualities such as oil layers, silicone-based sprays, and wax. The finest method for giving cloth water resistance and air permeability is coating and dyeing it. Similar to how we must utilize the material carefully when it comes to IR protection, failing to do so will prevent us from getting the greatest multipurpose tent. For example, we pay attention to both water repellency and air permeability because coating reduces the former. Because silica works better when it is in the form of nanoparticles, we use it. Different compounds, such as silver nanoparticles, copper oxide, copper sulfate, benzalkonium chloride, titanium dioxide, and zinc oxide, can be used to provide antibacterial qualities. Their chemical makeup and procedures are described below. ZnO nanoparticles[177−184] are what we utilize to add to the multifunctional tent because they mostly do not alter the tent's other features. One way to employ silver nanoparticles in textiles is to either immerse the fabric in a solution containing them or apply a silver nanoparticle solution to it. One way to employ copper compounds is to either immerse the fabric in a solution containing copper compounds or cover it with copper oxide or copper sulfate. You can utilize quaternary ammonium compounds, such as benzalkonium chloride, by immersing the fabric in the compound or coating it with a solution containing the compound. Various nanoparticle-based coatings such as titanium dioxide and zinc oxide can be used by applying a nanoparticle-based solution or coating to the fabric surface.

27. CONCLUSION

Herein, based on previous research, a highly profiled method for multifunctional tent is suggested for defense application. In this tent, IR protection, air permeability, antimicrobial, ultraviolet (UV) protection, and waterproof properties are suggested. The infrared (IR) protection in canvas fabric for tents can be achieved by coating methods that contain a variety of nanoparticles, including zinc sulfide (ZnS) and graphene oxide (GO), etc. The canvas fabric maintains its IR-protective characteristics while gaining improved antibacterial capabilities by the addition of extra/same coatings of zinc oxide (ZnO) or titanium dioxide nanoparticles. Furthermore, coatings with silica particles help to achieve water repellency without creating protective layers that are already in place. The permeability in this case will be achieved by graphene oxide, and UV protection will be achieved through the nanoparticles of ZnO. Therefore, the authors suggested materials that have multifunctionality properties like ZnO, GO, and ZnS. This novel method not only enhances the safety and comfort of users but also has the potential to completely transform the way that tents are used in humanitarian and military settings. A significant step toward improving outdoor shelter options in the face of changing environmental difficulties is the creation of an integrated tent.

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Notes

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