Advancement in UV-Visible-IR Camouflage Textiles for Concealment of Defense Surveillance against Multidimensional Combat Backgrounds

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Article

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Abstract

Target detection of defense technology is being rapidly upgraded with modern surveillance technologies. The latest techniques of surveillance are already being implemented for defense applications. Self-protection and hiding from opposing forces are the key principle for protection of special team in defense. Camouflage textiles aims to create confusing objects for target detection of military personnel. These textiles are applied for military protection such as clothing, weapon, vehicle and location hiding nets/tents, etc. The urgent need of camouflage textiles have been formulated with a technical solution and implementation of right camouflage materials for concealment of defense target signature against dry leaves, green leaves, tree bark-woodland combat background; water-marine combat background; sand-desertland combat background; stone-stoneland combat background; snow-snowland combat background; sky combat background and ice-iceland combat background, concrete-concreteland combat background (DGTWSICB) in ultraviolet-visible-infrared (UV-Vis-IR) spectrums. This hypothesis of optical & surveillance engineering has been coalesced for advancement of UV-Vis-IR-DGTWSICB camouflage textiles technology. The principle of camouflage engineering has been approached by broader spectrum probe in UV-Vis-IR rather than Vis ranges only. Furthermore, single formulation of camouflage textiles has been proposed for multidimensional CBs-DGTWSICB. Electromagnetic spectrum, reflection, electron energy, photonic signal and imaging mechanism in UV-Vis-IR have been presented for optical engineering of concealment, detection, recognition and identification of target signature against DGTWSICB. Spectrum relationship of camouflage materials and DGTWSICB materials have been illustrated and compared in UV-Vis-IR spectrums. Camouflage material design, method design & spectral design; adaptive camouflage; techniques for camouflage textile assessment for digital camera and hyperspectral camera imaging; image processing techniques and a hierarchical model have been demonstrated for augmentation of camouflage textiles in UV-Vis-IR illumination. Therefore, anticipated design of camouflage textiles may enhance high-performance innovation for modern surveillance of military protection related to digital camera, hyperspectral camera and radar. This hypothesis includes advance guideline for camouflage textiles design for CBs-DGTWSICB.

1 Introduction

Surveillance technology in visible range camouflage and detection is practiced by military professional. Modern battlefield has been a great challenge due to advanced surveillance of broaden electromagnetic spectrums in ultraviolet-visible-near infrared (UV-Vis-NIR) ranges [1, 2]. Camouflage textiles designates an artificial masking process of target object with combat background (CB) by adaptation of pattern, texture and chromatic characteristics [3]. Concealment can be defined as perceptive interface between observer/digital camera/hyperspectral camera and target signature by which camouflage textiles are not visualized to detect antagonistic (enemy) of opposition team. Camouflage textiles would allow an object to blend into its surrounding combat environment by optical mechanism of color matching or luminosity. The scale of concealment and detection is identified by its degree of adaptability which means a capability of an adapting object (appearance) to match its CB. The concealment of camouflage textiles can be designed by means of spectrum probe under specific CB and/or multidimensional CB environments [4]. Camouflage textiles are the general practice by defense professional for hiding weapons, location and humans from opposition team. Presently surveillance technologies have been advanced in extended electromagnetic spectrums in UV-Vis-NIR. There is enormous limitation of technologies to fulfil the current requirements of camouflage textiles against multidimensional CBs such as dry leaves, green leaves, tree bark-woodland combat background; water-marine combat background; sand-desertland combat background; stone-stoneland combat background; snow-snowland combat background; sky combat background; ice-iceland combat background and concrete-concreteland combat background (DGTWSICB). It is necessary to improve camouflage textiles for target concealment and protection of defense professional against multidimensional CBs-DGTWSICB in UV-Vis-IR spectrum [1].

1.1 Overview of camouflage textile design and engineering of advancement

Camouflage materials and camouflage assessment has become a vibrant segment of defense research for protection of special team in defense who are always playing with enemy as part of daily responsibilities of defense profession, this is an ongoing research headache to the defense and color scientist. There is enormous lacking in standardization of camouflage materials and methodology for right concealment of target signature. An overview of deceiving materials selection for camouflage textiles formulation and methodological steps of camouflage textiles assessment have been demonstrated for concealment of target signature against CB. The properties of Vis-IR reflection of materials, pigmentation, nanomaterials, thermochromic dyes, thermal insulation and synthetic dyes have been critically discussed in terms of camouflage material properties and its advancement for suitability of defense textile applications. The camouflage mechanism of CDRI of defense target signature have been represented by chromatic appearance of target object and CB, digital camera/hyperspectral camera assessment and image processing technique. Therefore, a hierarchical model for camouflage textiles formulation and assessment of CDRI have been proposed for simultaneous spectrums in UV-Vis-IR/specific spectrums in UV/Vis/IR for defense applications against multidimensional CBs-DGTWSICB.

1.2 Optical engineering of camouflage textile design against multidimensional CBs-DGTWSICB

Figure 1, the design of camouflage textile has been patented in visible ranges having limitation with multidimensional CBs-DGTWSICB and broader electromagnetic spectrums. Current camouflage textiles [3, 5–10] have been augmented in Vis and limited spectrum probe in IR, but the reflection is still visible due to the reflectance of CB materials such as leaves, bark, branches, grasses and other background materials. Camouflage textile particularly depends on chromatic adaptation with CB in terms of spectral reflectance and its variations. Reflection profile of DGTWSICB materials are the demanding fact for the development of real concealment of camouflage textiles in UV-Vis-IR spectrums against multidimensional CBs-DGTWSICB [1, 11, 12]. Spectral reflectivity is the optical principle for chromatic and achromatic deviation of target signature. For example, marine camouflage textiles are influenced by water color, and optical properties in terms of background [13]. Reflection profile of every CB differs in UV-Vis-IR spectrums. Reflectance of woodland CB is a matter of ‘chlorophyll’ referred to chromatic adaptation of green color (fresh leaves) background [14]. Textile dyes such as vat, disperse, reactive, sulphur, acid, thermochromic materials, electrochromic materials, IR reflective pigments, metal oxides such as iron oxide, nanoparticle such as titanium dioxide are being practiced with textile coloration and coating/printing process for development of camouflage textiles. The combination of right camouflage materials and development of demanded camouflage textiles have been limited in multidimensional spectrums and CBs. It is necessary to establish actual deceiving materials formulation and standard process for concealment of target signature in terms of reflection, gloss, texture and color with CB in UV-Vis-IR [11, 15–17]. Spectral reflectance between target signature and surrounding CB of geographical regions should match for the concealment of defense target. The evaluation process of concealment and its accuracy are also considered as a complicated process of assessment due to time consuming and labor-intensive way of field trialling. Spectral and photographic analyses in UV-Vis-IR are the optical advancement for concealment, detection, recognition and identification (CDRI) of target signature against CBs-DGTWSICB [2, 18–22].

2 Framework Of Innovative Approach For Uv-vis-ir Camouflage Textiles

The key contributions of camouflage engineering in UV-Vis-IR spectrums have been approached in terms of nine phases of advancement for camouflage textiles, this study have been found a new direction of camouflage chemistry and camouflage physics under focusing on camouflage materials design, method design, CBs-DGTWSICB and extended spectrums which is beyond of existing idea of present literature. This hypothesis of camouflage design is applicable for high-performance camouflage research for defence protections in digital imaging and hyperspectral imaging.

1. Advancement phase-1, illumination principle for CDRI of target signature in UV-Vis-IR spectrums against multidimensional CBs-DGTWSICB.

2. Advancement phase-2, UV-Vis-IR engineering for camouflage textiles formulation against CBs-DGTWSICB.

3. Advancement phase-3, Exponential relationships of multidimensional CBs- DGTWSICB in UV-Vis-IR spectrums.

4. Advancement phase-4, Hypothesis of camouflage textiles design in UV-Vis-IR illumination against CBs-DGTWSICB.

5. Advancement phase-5, Materials design for camouflage textile coloration against CBs-DGTWSICB under UV-Vis-IR spectrums.

6. Advancement phase-6, Method design for CDRI measurement of target signature against CBs-DGTWSICB under UV-Vis-IR spectrums.

7. Advancement phase-7, Significant advancement of camouflage textiles against modern defense surveillance in UV-Vis- NIR spectrums.

8. Advancement phase-8, Principle of optical approach for camouflage textiles coloration for concealment against digital camera imaging/hyperspectral imaging in UV-Vis-IR spectrums .

9. Advancement phase-9, Hierarchical model for camouflage textiles formulation and assessment of CDRI against CBs-DGTWSICB.

3 Advancement Phase-1, Illumination Principle For Cdri Of Target Signature In Uv-vis-ir Against Multidimensional Cbs-dgtwsicb

The optical mechanism of CDRI in UV-Vis-IR camouflaging, chromatic appearance, spectral frequency, electron energy versus photonic signal for digital camera imaging and hyperspectral camera imaging have been demonstrated by the ‘reflection engineering’ and ‘imaging theory’ in the vein of wavelength-reflection-electron energy-photonic signal. Figure 2 and Equ. 1–7; CDRI principle has been illustrated according to established theory of wavelength-reflection-electron energy-photonic signal such as Einstein theory of energy [23], Broglie relation of wavelength [24] [25], Snell’s law of reflection [26, 27] and photon energy of Max Planck [28]. Illumination in the form of energy creates photonic signal for surveillance and imaging of target signature against multidimensional CBs-DGTWSICB.

3.1 Principle of optical engineering for CDRI in UV-Vis-IR spectrums

From Eqs. 1 and 2, we can find the difference between the angular momentum of target signature and CB materials-DGTWSICB for CDRI of target signature.

$\lambda = h/P = h/mv$ Eq. 1

Where, λ = wavelength of electron; Planck’s constant, $h = 6.6 \times 10^{-34}$ kgm^2/s; P is the momentum of target CB materials or target signature, the P value manipulates the value of λ in UV-Vis-IR and chromatic appearance of target signature or target CB materials; m = mass of electron of target signature; and v = velocity of electron. By putting the value of h, m, and v in Eq. 1, we can signify the wavelength. Wavelength in UV-Vis-IR spectrums controls spectral frequency-electron energy-photonic signal for chromatic and achromatic appearance/digital imaging/hyperspectral imaging of target signature against CB materials-DGTWSICB.

$P = \frac{mv}{\sqrt{1 - V^2/c^2}}$ Eq. 2

Where, P is the electron angular momentum of target signature; m is the mass of electron of target signature; v is the velocity of electron of target signature; and c is the velocity of the light. By putting the value of m, v, c; we can find the angular momentum of target signature at different CB locations.

3.2 Optical principle of refractive index and reflection for CDRI in UV-Vis-IR spectrums

By putting the value of i and r in Eq. 3, we can find the refractive index of target CB and target signature.

$n = \mathrm{Sin}(i)/\mathrm{Sin}(r)$ Eq. 3

Where, i is the angle of incidence and r is the angle of refraction.

From Eq. 3, the difference of angle of refraction (Δn) for CDRI can be determined using Eq. 4,

$\Delta n = n_1 - n_2$ Eq. 4

Where, n_1 and n_2 are the refractive index of target CB and target signature. By putting the value of n_1 and n_2, we can signify CDRI of target signature against surrounding background in UV-Vis-IR. The value of n_2 will be almost zero or infinitive when the target signature will be high reflective or zero reflectance; hence the target will be concealed against CB. The minimum/maximum value will identify CDRI of target signature against CB.

Spectral and imaging signal of CDRI depends on velocity of light. From Eq. 5, the difference of velocity of light between CB and target materials for CDRI can be determined.

$\Delta v = c/n_1 - c/n_2$ Eq. 5

Where, c is the constant speed of light; c/n_1 determines the velocity of light of CB materials, and n_1 is the value of refractive index of CB materials; c/n_2 determines the velocity of light of target signature and n_2 is the value of refractive index of target signature.

3.3 Optical principle of electron energy and photon signal for CDRI in UV-Vis-IR spectrums

By determining the energy of photon signal of target CB and target signature, we can indicate CDRI of target signature against surrounding CB in UV-Vis-IR spectrums. When the difference of electron state between target signature and target CB nearest of zero or infinitive, the photon signal will follow the energy response to the camera sensor for imaging and spectral frequency of target OB. Therefore, the target signature will be concealed/confused against background materials, CBs-DGTWSICB. The higher energy difference for target CDRI, ΔE, as shown in Eq. 6 will signify the higher number of photons to the camera sensor for detection, recognition, and identification, respectively.

$\Delta E = h\, c_1/\lambda - h\, c_2/\lambda$ Eq. 6

Where, Planck’s constant, $h = 6.6 \times 10^{-34}$ kgm^2/s; λ is the wavelength of electron; the term $h\,c_1/\lambda$ determines the energy of photon signal of target CB materials, and c_1 is the velocity of the light for imaging of CB materials; the term $h\,c_2/\lambda$ determines the energy of photon signal of target signature, and c_2 is the velocity of light for imaging of target signature.

3.4 Optical principle of spectral reflectance for CDRI in UV-Vis-IR spectrums

If target signature shows zero reflection, the electron energy of photon signal states at the rest position of acceleration. At rest position of electron is considered for a target signature of zero reflection materials; and a voltage difference is considered as V volts. The wavelength for identifying CDRI can be determined by using De Broglie equation of wavelength Eq. 7.

$$\lambda = h/P = h/mv = h/\sqrt{2meV} = \frac{6.6\times10^{-34}}{\sqrt{2\times9\times10^{-31}\times1.6\times10^{-19}\times V}} \quad \text{Eq. 7}$$

Where, Planck’s constant, $h = 6.6 \times 10^{-34}$ kgm^2/s; constant mass of electron, $m = 9.1 \times 10^{-31}$ kg; constant electron charge, $e = 1.6 \times 10^{-19}$ C; v is the velocity of electron energy carried by photon for creation of imaging signal.

For low reflection/zero reflection materials, electron velocity (v) will be almost zero; and for high reflection materials the electron velocity (v) will be infinitive. Therefore, spectral signal will not be detected for the chromatic appearance and the target signature will be denoted as concealed. Accordingly, detection, recognition, and identification of target signature will be signified by the specific value of velocity of electron energy.

4 Advancement Phase-2, Uv-vis-ir Engineering For Camouflage Textiles Formulation Against Cbs-dgtwsicb

4.1 Optical principle of electron energy versus sun radiation for design of UV-Vis-IR camouflage textiles

Figure 3a & 3b, an exponential graph has been illustrated to simplify the spectral relationship between electron energy and sun radiation in UV-Vis-IR spectrums. Here, total energy of sunlight are classified into UV-Vis-IR spectrums. UV band, 200–400 nm stores 5% of total energy, Vis band, 400–720 nm stores 45% of total energy and NIR band, 720–2500 nm stores 50% of total energy [29]. 99% sun radiates between 200–4000 nm in chromatic condition of visible ‘red ray’. Electron energy, E (eV) of sun radiation changes in UV-Vis-IR spectrums. The summarized data information have been cited in Table SI. 1 (a, b). The vibration of electron energy shown in Fig. 3a and sun radiation shown in Fig. 3b are significantly higher in UV-Vis spectrums and dramatically declines in IR spectrums. Electrons of object-background (OB) materials combines with photon from the light of surveillance device to form chromatic intensity versus imaging of target OB materials. Electron energy and photonic combination generates the intensity/imaging of target OB in different wavelength of UV-Vis-IR. The flow of electron energy is almost constant in entire spectrum of UV-Vis-IR; comparatively higher in UV, medium in Vis and lower in IR spectrums. Photon direction is a matter of altering trichromatic reflection to the imaging sensor. This optical condition of imaging is controlled by electron energy of OB materials and its related interferences. Choosing the reflection matching materials with multidimensional CBs-DGTWSICB for textile formulation may signify the target concealment in UV-Vis-IR spectrums. In optical engineering, replacement of wavelength changes the electron energy from target signature to the camera sensor. Electron energy creates the variation of refractive index, which alters the appearance of target signature to the imaging sensor. Lower electron energy is the limitation of conventional ‘color matching theory’ in IR camouflaging. Hence, reflection changing materials may be an optical solution of IR camouflaging or simultaneous camouflaging in UV-Vis-IR spectrums for optical matching of target signature against multidimensional CBs-DGTWSICB [30–32].

4.2 Reflection versus chromatic signal for formulation of UV-Vis-IR camouflage textiles

Snell’s law is much related illustration for reflectance characteristics of target OB. According to Snell’s law of reflection, the speed of light rays decreases when travelling to refractive medium [26, 27]. The refractive indexes of International Commission on Illumination (CIE)-red, green, and blue (RGB) color at different wavelength in UV-Vis-IR are not similar. Such as: refractive index of red color is 1.50917 at wavelength 640 nm, yellow 1.51124 at wavelength 589 nm, green 1.51534 at wavelength 509 nm, blue 1.51696 at wavelength 486 nm and violet 1.52136 at wavelength 434 nm. Illumination parameters such as: refractive index, reflection angle (0° to 360°) and wavelength determines the chromatic signal of target signature and CBs-DGTWSICB to the sensor of digital camera and hyperspectral camera in UV-Vis-IR spectrums. Hence, the chromatic appearances of target OB are replaced when reflectance coefficients (0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0) are shifted as spectrum probe shown in Fig. 4 [27, 33]. Reflection coefficients are also related to OB properties in UV-Vis-IR spectrums. Surface gloss depends on surface smoothness or irregularity. Gloss is higher on smooth surface and lower on irregular surface [19, 29].

4.3 Geometrical theory of reflection for design of UV-Vis-IR camouflage textiles against CBs-DGTWSICB

The key principle of UV-Vis-IR camouflage textiles is minimizing the difference of light scattering or radiating properties between target signature and CBs-DGTWSICB. Hence the concealment of camouflage textiles depicts a fake target to appear an optical mechanism of artificial cheating with opposition team [34]. Sequentially, camouflage textiles are specified in terms of illumination of target signature and CBs. The angle of reflection depends on the direction of incident light beam from OB. The ratio of speed difference of light striking denotes the refractive index of OB. Light obstacle is also a fact of camouflage object as predicted by ‘geometrical ray theory’ when light passes through a tiny hole known as ‘diffraction’. This optical mechanism creates uneven shadow and reflection to the imaging device. Practically light waves from sun light and camera sensor are not similar, so the optical interference occurs when two overlapping of light from unlike sources. A maximum value of refractive index generates the high bending of light. Absorption is a process of transfer energy from the electromagnetic wave to the atom of target signature and CB substances. The energy can create excitation of electron into higher energy state, and it depends on wavelength spectrums of light in UV-Vis-IR. Therefore, absorption-transmission-reflection (ATR) of OB is the key principle behind the camouflage coloration. Optical scattering is an energy removal process of light beam depending on structural composition of OB. Optical transmission depicts the weakened absorption and scattering when OB states behind open space in combat environment, CBs-DGTWSICB [35, 36].

4.4 Reflection principle for camouflage measurement in UV-Vis-IR spectrums

Camouflage textiles are possible to be designed to have irregular chromatic combination, reflection matching and perforation of surface under consideration of specific CB [37]. The ATR of chromophore group differs in UV-Vis-IR spectrums. The intensity of ATR creates chromatic variation [38]. Design of camouflage textiles are related to color, contrast, lightness, shape, texture and depth of object-background (OB) materials. Hyperspectral camera captures the color outlook of every pixel in the image of target object and CB. Color difference between OB can be depicted by hue, chromaticness and lightness. Spectral behavior and reflection properties of target signature at specific wavelength is a key fact for camouflage textiles with any CB as light is simultaneously reflected from the target OB. Reflection of OB is highly influenced by natural illumination, inter-reflections of existing molecules in atmosphere, air density and temperature differences. The perceived/imaging color and the measured actual color may have some differences. So there are limitations of accuracy for camouflage measurement in laboratory rather than field trialling [39]. CB has many reflectance spectra depends on angle of light falling on background and angle of illumination of digital camera/hyperspectral camera [33].

5 Advancement Phase-3, Exponential Relationships Of Multidimensional Cbs-dgtwsicb In Uv-vis-ir Spectrums

Figure 5 shows the spectrum relationships of DGTWSICB such as woodland CB: grass/green leaves [40] (Fig. 5a), tree bark [41] (Fig. 5b), vegetation and deciduous tree [40] (Fig. 5c); snowland, iceland and marine CB: snow (Fig. 5d), ice (Fig. 5e), water [42] (Fig. 5f); desertland CB: [43] sand [44] (Fig. 5g, 5h) [41] (i); sky and urban CB: sky [45] (Fig. 5j), red brick and concrete [40] (Fig. 5k). Spectral data information are summarised through published literature, a supporting information is attached in Table SI. 1, c-m. Every exponential spectrum has been illustrated to represent a common spectral coefficient of CB in UV-Vis-IR[32, 46]. These exponential spectra typically signifies the expected spectra of camouflage materials under single/multidimensional CBs-DGTWSICB. Spectral characteristics of individual CB needs to consider for camouflage coloration against single/adaptive CB under UV-Vis-IR spectrums.

6 Advancement Phase-4, Hypothesis Of Camouflage Textiles Design In Uv-vis-ir Illumination Against Cbs-dgtwsicb

6.1 Optical principle of technical materials versus synthetic dyes for camouflage textiles in simultaneous spectrums probe

Figure 6a & 6b, illustrates a general comparison of exponential relationships between high reflection materials and synthetic dyes. Reviewed data are summarized and cited in Table SI. 1 (o) [31]. Figure 6a, aluminium, rhodium and titanium particle shows almost straight line in UV-Vis-IR spectrums as sequence of aluminium > rhodium > titanium > copper > silver > gold. Such high reflection materials may signify as camouflage materials in UV-Vis-IR due to random/infinite photonic response to the imaging device. Figure 6b depicts the exponential relationships of synthetic dyes which shows the completely reverse behavior in UV-Vis-NIR spectrums. Chrysoidine, Orange 2, Lithol fast scarlet-RNP are the synthetic dyes of monoazo group, Chrysophenine G is a synthetic dye of diazo group and Flavophosphine is a dye of acridine group. These groups of synthetic dyes are very common for textile coloration in terms of CB matching in Vis spectrum. Therefore, camouflage textiles coloration in simultaneous spectrum probe needs to choose alternative materials rather than synthetic dyes only or technical formulation of synthetic dyes. The UV-Vis-IR spectrums of synthetic dyes and high reflection materials have been classified as low and high amplitude of signal. Figure 6a, 6b; in comparison, synthetic dyes are remarked as deviation of high amplitude and high reflection materials are signified as variation of low amplitude. Few high reflection materials have almost zero deviation of amplitude and hypothetically remarked as UV = Vis = IR and Vis = IR referred to Table 1. Electron density significantly decreases when spectral amplitude/intensity in negligible range [47, 48]. There is a possibility of capturing a minor deviation of photonic signal to the imaging sensor in UV-Vis-NIR illumination. Accordingly, reflectance profile of CB varies in UV-Vis-NIR region [14]. The reflection factors of CB such as tree branches, leaves, soil, rocks, water differs 10–80% for CDRI mechanism [49]. The difference of reflection between target object (camouflage textiles) and CB determines the chromatic adaptation (CIE RGB, L*, a*, b*) versus CDRI. Reflection properties of CB are the parameters of CDRI for target signature [50]. The threat of reflection is also related to the surrounding CB materials rather than specific known materials of CBs-DGTWSICB [6]. Therefore, optical hypothesis of simultaneous spectrum probe camouflage textiles in UV-Vis-NIR ranges are critical due to deviation of reflection phenomenon from signature and CBs.

6.2 Optical principle of materials design for camouflage textiles in simultaneous spectrums probe

Figure 7, Vis-IR coefficients of black color and high reflection materials (shiny surface) are represented at similar pixel position. A simultaneous photonic signal in Vis-IR is illustrated by the sum of Vis and IR amplitude. The data information have been attached in Table SI. 1 (n). The variation of photonic signal is significantly higher in Vis than IR. Heat in IR region increases emissivity of OB and declines the reflectance of OB. This IR mechanism is responsible for minor photonic signal to remote sensing device of digital imaging/hyperspectral imaging. In IR spectrums, the photonic response of black color is comparatively higher than high reflection materials as shown amplitude. Oppositely, photonic signal of black color is lower than high reflection materials in Vis spectrums. Hence the hypothesis states that the combination principle of such materials may signify simultaneous camouflage in UV-Vis-IR spectrums [51].

6.3 Optical principle of technical formulation of UV-Vis-IR camouflage textiles

UV-Vis-IR camouflage textiles is proposed by treating with metallic reflection materials such as aluminum, copper, zinc. Camouflage pigment such as chromium oxide has reflection property like ‘chlorophyll’ for reflection adaptation of target signature with woodland CB. Alternatively, carbon black pigment (CBP) has high absorption and low reflection property in IR spectrums. Thermal transparent binder such as polyethylene vinyl acetate copolymer, chlorinated polypropylene are suitable for camouflage treatment as the binder cannot change the reflection. Currently developed camouflage textiles can be detected from CB in NIR spectrum. Military vehicle produces heat by internal combustion engine, terrestrial thermal emissions. The adaptation of emission between OB needs to maintain for concealment of target signature. Temperature is a cause for making contrast between target signature and CB. Thermal insulation can be used for camouflage textiles when the surface temperature difference from the environment is more than 10˚C. Application of thermal insulation materials is an option for secure protection and structuring UV-Vis-NIR camouflage textiles such as vehicle net. Such fabric also protects against radar spectrums (3 GHz to 3000 GHz) [12, 17, 52, 53].

Camouflage textile materials in IR range are made from synthetic fiber having ‘chlorophyll’ like reflectance characteristics in IR range such as polyamide and polyester [54]. High reflection in multidimensional direction to the viewing angle depicts the concealment of target location. The high reflection light theory is applied on camouflage for submarine concealment as marine camouflage. Reflective metallic coatings of aluminum copper or zinc on the base layer achieve high reflectivity in the entire IR spectrums, but the technology has limited applications of camouflage textiles for concealment in UV-Vis-IR spectrums against multidimensional CBs-DGTWSICB. The protection against radar detection is achieved with coated materials for effectively reflecting radar radiation in all directions[55] [16, 56, 57].

6.4 UV-Vis-NIR camouflage textiles for concealment of hyperspectral camera against defense surveillance

Hyperspectral camouflage means the protection of target signature from surrounding CB in terms of hiding of hyperspectral surveillance in UV-Vis-NIR spectrums. Chromatic blending of objects (camouflage textiles) with CB environment is the first attribute of hyperspectral camouflage textiles. Camouflage depends on shape, size, hue, color contrast and mobility of target object with CB. Differences of ATR, scattering, diffraction and polarization of light between target OB identify the detectability/adaptability of target object against CBs-DGTWSICB. Hyperspectral, thermal, NIR, multispectral, anti-radar camouflaging are critical for the survivability of defense professional. UV and NIR sensors of hyperspectral camera have been created a great challenge of hyperspectral camouflage. Recent augmentation of camouflage textiles only covers Vis ranges camouflage although there is limitation of concealment in multidimensional CB environments in terms of lacking right materials, methodology and standardization. Recently developed camouflage textiles cannot fulfill the protection of UV-IR ranges surveillance technology in the vein of hyperspectral camera/digital camera. Colorant manufacturers are also struggling for camouflage dyes, but a right formulation is still a challenging fact. NIR reflectance dyes or pigment coating, aluminum coated glass thermally bonded into nonwoven, glass fabric and nonwoven fabric combination can be comprised in terms of photochromic (light) and thermochromic (heat) mechanism of camouflage textiles for augmentation of NIR camouflage. The simultaneous camouflage textiles in UV-Vis-NIR ranges are also critical to the research community, the technology needs to coalesce through optical mechanism of OB and suitable material design for camouflage textiles coloration [19, 20, 55, 58, 59]. Figure 5, 6, 7; the reflection coefficients and exponential trends of multidimensional CBs-DGTWSICB in UV-Vis-NIR have been remarkably noted and hypothetically categorized in Table 1. This concept can be hypothetically implemented for design of camouflage materials in UV-Vis-NIR spectrums.

Table 1

Summarised exponential relationship of electron energy/photonic response among multidimensional CBs materials and materials for textile coloration in UV-Vis-IR spectrums.

Multidimensional CBs materials	**Electron energy/photonic response**	**Materials for textile coloration**	**Electron energy/photonic response**
Woodland	NIR > Vis > UV	Synthetic dyes (Five different)	NIR > Vis > UV
Snowland	UV > Vis > NIR	Aluminium	UV = Vis = IR
Iceland	UV > Vis > NIR	Rhodium	Vis = IR
Marine	UV > Vis > NIR	Copper	IR > Vis > UV
Desertland	IR > Vis > UV	Titanium	IR > Vis > UV
Soil	IR > Vis > UV	Silver	IR > Vis > UV
Sky	UV > Vis > NIR	Gold	Vis = IR
Urban	NIR > Vis > UV	Shiny surface	UV = Vis = IR

7 Advancement Phase-5, Materials Design For Camouflage Textile Coloration Against Cbs-dgtwsicb Under Uv-vis-ir Spectrums.

7.1 Optical principle of camouflage pigmentation for Vis-IR range concealment

Simultaneous applicable Vis-IR camouflage is proposed based on metal-based structure of SiO_2/Ag/ZnS/Ag [55, 60]. For simultaneous pigmentation in Vis-IR, pigment should have simultaneous transparent in Vis-IR ranges. Vis camouflage textiles can be designed by dark color or minimum gloss pigmentation such as CBP, perylene black as the selective absorber. Metal oxide increases the concealment in NIR and thermal IR ranges. Metal oxide absorbs in NIR range, and these are transparent in thermal IR range. Metal oxides (CeO_2, TiO_2, MgO, ZnO) shows high reflection in simultaneous Vis-IR. The reflection variations between Vis-IR are nearest of 5%. As hypothetical example, Fig. 8 depicts the exponential relationship of ZnO pigment in Vis-NIR. Reviewed data information are cited in Table SI. 1 (q). Metal flakes such as aluminium has strong reflection in both Vis-IR spectrums. Red iron oxide and titanium dioxide have minimum scattering effect of light without altering the reflectance shape. Particles of 1 mm red iron and titanium dioxide scatters NIR radiation at 2.3 mm. Refractive index of titanium dioxide and chromium oxide are 2.81 and 1.90 and their scattering powers (square meter) are 1.90 and 1.28 respectively. Titanium dioxide (mean particle size 10 μm) reflects between 800 nm and 2300 nm; and comparatively less reflection is noted in 400–800 nm. Such compounds have atomic mobility and light striking capability of target signature at very high incident angle. There is possibility of electron trapping between target signature and CB which mechanism may generate minor energy for photonic signal to the remote sensing device. Hence, the light is also expected to scatter very quickly to the surrounding area of CB. The photonic signal of metal oxides to the spectral sensor cannot capture enough photon whatever need to generate an appropriate imaging signal of target signature against CB. High reflection spectral signal may defend for genuine pixel formation of target signature to the imaging sensor. Therefore, the target signature may be confused or concealed by the modern remote sensing mechanism of target detector [29, 61–63].

Commercial pigments are available such as CI pigment green 17, 26 and 50, CI pigment brown 29 and 35, pigment blue 28 and 36, pigment black 12; white pigment base are also available such as white pigment titanium dioxide or zinc white, calcium carbonate, barium sulphate, alumina, silica, clay, aluminum powder, etc.; metal oxides such as zirconium oxide, thorium oxide, etc.; metallic pigment such as aluminum, mica flakes, etc.; high refractive index pigments such as titanium dioxide, chromium oxide, zinc sulphide, zinc oxide, aluminum, gold, silver, copper, etc. Combination of different IR reflective pigments may enhance the total reflection of coated surface. Particle size can be selected from 0.35 to 0.55 microns [31, 64]. Chromium oxide, iron oxide and carbozel violet pigments are remarked as camouflage pigments due to reflectance properties both in Vis and NIR [50]. A deep color camouflaging formulation is implemented on aircraft when the CB is considered as dark sea. Colors are formulated by titanium dioxide, organic perylene black and red, blue, yellow oxide based on polyurethane (PU) resin (hexamethylene diisocyanate). Microfine silica is also used as gloss reducing agent. Grey color formulation is used for countershaded aircraft [65]. IR pigments (chrome oxide green, carbon black, etc.) have great advantages for simultaneous camouflage in Vis-NIR. The pigmentation technique allows the color matching with specific CB in Vis, the reflection principle allows to blend the target signature with CB color in NIR range [50]. Synthetic coloration with low reflection materials such as CBP declines the detectability in Vis range and there is scope of NIR range experimentation [66]. CBP is a traditional colorant. It absorbs UV-Vis-NIR wavelength of light. The particle size denotes the physical properties of the pigmentation such as color strength, stability and light scattering ability. Even a small amount of IR-absorbing material on total weight can significantly reduce IR reflectivity. Reflection of objects can be tested using UV-Vis-NIR spectrophotometer in optical mechanism of ATR [31, 67].

7.2 Optical engineering of synthetic pigmentation for simultaneous camouflage in Vis-NIR against woodland CB

Synthetic pigmented surface has properties of NIR reflection. Pigments are synthesized by the mixtures of metal hydroxide, nitrates, acetates and oxides at very high temperature ranges over 1000°C. Metal and oxygen ions are oriented in a stable crystal structure, the process is called ‘calcination’. IR reflective coating is highly used for building construction; it can also minimize the surface heating on textile substances. IR reflective pigments are suitable for NIR camouflage textiles for reducing the heating effect on color changing. Remaining high percentage of mobile electrons depicts high reflection on surface. Functional properties of calcinated pigments have dual action of absorption and reflection. Pigment absorbs light in visible region and appropriate for Vis camouflage. The pigmentation technology of dual camouflaging seems more accurate for concealment of Vis-NIR camera surveillance. For example, ‘chlorophyll’ of green plants reflects IR light. Green plant of woodland CB contains ‘chlorophyll’, and it has organic pigment of IR reflection. ‘Chlorophyll’ is also termed as natural IR reflective material, applicable for woodland camouflage textiles. Practically tree background is cooler than surrounding background in hot summer [31, 64].

7.3 Optical engineering of thermal insulation for camouflage formulation

Planck’s law derives that IR range is mostly related to thermal radiation. Hence, IR camouflage textiles needs the combination of thermal insulation materials. Silica aerogel has thermal insulation property which can reduce the surface temperature of camouflage textiles. Phase change materials have found limited applications for camouflage textiles. For consideration of concealment, germanium is a high IR reflective material for target confusing versus camouflaging response. Thermal insulation-reflection combination of silica aerogel and germanium is proposed for NIR range camouflage textiles for aircraft and missile target protection. High temperature aircraft nozzles and high temperature naval ship funnels are also challenging for design of sky camouflage and marine camouflage. The real protection of fighting aircraft and marine ship is still challenging [68]. A combination of thermal insulation and high reflective coating has been commented to be more effective for defense target concealment [69]. NIR anti-reflection coating is formulated by the combination of silicon and germanium [70]. The concept of technology in NIR range camouflage textiles have been limited still now. There is feasibility of NIR range camouflage incorporating with combination of phase change materials such as $Ge_2Sb_2Te_5$ [71] and VO_2. The combination has phenomenon of phase transition and reflection changing for NIR camouflaging [72]. Surface reflection of camouflage textiles depends on treatment with suitable materials. The mechanism defines the reflection and transmittance of OB as referred by the theory of ‘Augustin-Jean Fresnel’. Low reflection coatings and fabrication design are another way of camouflage principle [73]. IR absorbing CBP can be applied for enhancement of IR absorption.

7.4 Optical engineering camouflage coloration with nano materials

TiO_2, ZnO, Fe_2O_3 nanoparticles were applied for IR protection. Camouflaging nanobeads can be used with textile dyes for deceiving formulation of camouflage coloration. There is advance suitability of nano materials for camouflage clothing. Nano materials can enhance defence textile properties such as fabric softness, durability, breathability, water repellency, fire retardancy, antimicrobial, UV protection, shrink proof, etc [74]. Nano titanium dioxide increases surface reflection [75]. Cotton-nylon blended fabrics are printed using a mixture of pigments and carbon black nanoparticles for camouflage coloration. Shading of brown, olive green and khaki was employed in desert uniform. Printing formulation remarked as significant decline in limited ranges of NIR reflectance [76, 77]. The structure of camouflage coloration is also formulated by core (chromophore materials) and sheath (polymer) process [38]. A polyvinylidene fluoride resin can be used as the transparent binder [29].

7.5 Optical engineering of camouflage coloration with thermochromic dyes

Thermochromic colorant can be blended with pigment for matching signature with CB environment. Thermoplastic PU and graphite are mixed; and coated for thermochromic coloration. Thermochromism and camouflage coloration can be tested by CIE red, green, blue, L*, a*, b*. These values/imaging properties can be recorded before and after heating for assessment of IR camouflaging against selected CB [78, 79]. Liquid crystal is also a unique material for temperature responsive fabrication. Chiral nematic liquid crystal changes its color in the presence of thermal, electrical and optical stimuli; the phenomenon is responsible for changing refractive index or pitch. Formulation of indolylfulgide chiral dopants shows color stable adjustment. The color stability of chiral nematic liquid crystal has been observed for smart applications of camouflage textiles [15, 80]. The thermochromic dye ‘crystal violate lactone’ was used as core material; and silica was used as shell material. The thermochromic effects and color reversibility were observed at wavelength 610 nm under consideration of shifting color strength, K/S value from 12 to 2 [81]. Hence thermochromic colorant may have feasibility for camouflaging against selected CB.

7.6 Optical engineering camouflage coloration with synthetic dyes

Cotton, polyester, nylon and cotton-polyester blends are in general applications of camouflage textiles [82]. Nomex and Kevlar are suitable for high-performance applications of camouflage textiles. Spun bonded nonwoven fabric is experimented for randomly orientation of metal fibril on the fabric surface to obtain expected camouflage formulation. Filling of hollow fiber with liquid dyes and solid pigment is a proposed technique for adaptive camouflage textiles [83]. Common methods of fabricating camouflage textiles are dyeing, coating and printing [84]. Coating and printing are suitable techniques for manmade or natural fiber based camouflage textiles [43, 66]. Printing is a method of camouflage patterning. Camouflage patterns on fabric are produced using low reflectance dyes having thiazine at relatively long wavelength greater than 900 nm [85]. The reflectance profile of woodland camouflage textiles is experimented by different disperse dyes such as CI disperse black, CI disperse yellow 23, CI disperse blue 14 and disperse blue 56. The reflectance of camouflage treated objects and greenish leaves background was compared with CIE L*, a*, b*, c*, h for chromatic variation. The process interprets a minimum level of woodland camouflaging, it has demanded for further level of experimentation. CI disperse blue 56 shows the effect of green leaves camouflaging on polyester fabric [14]. Vat blue 13 dye has also green camouflaging property in Vis and limited NIR region [86–88]. Vat dyes have low IR reflectance and good fastness properties, suitable for camouflage applications on cotton textiles. Tetraaryldiamine dyes absorbs in IR [89].

8 Advancement Phase-6, Method Design For Cdri Measurement Of Target Signature Against Cbs-dgtwsicb Under Uv-vis-ir Spectrums.

8.1 Spectrometry and colorimetry versus CDRI assessment

In general, the wavelength more than 700 nm is considered as IR range. The visible spectrums covers wavelength from 400 nm to 700 nm. The wavelength 200 nm to 400 nm is depicted as UV spectrums. Both UV and IR rays are invisible for human due to lacking of receptors. Ray directions are a matter of light reflection such as specular reflection and diffuse reflection. Single outgoing reflection is termed as specular reflection and multiple angle reflection is termed as diffuse reflection. A color measurement spectrophotometer can be used to measure reflectance, transmittance or absorbance of target OB at different wavelength. A specular included method is used for total reflection and a specular excluded method is used for diffuse reflectance of OB substances. The color variation of specular included and specular excluded is verified by ceramic tiles of 12 standard reference color (white, pale grey, middle grey, deep grey, orange, deep pink, black, red, bright yellow, green, cyan, and deep blue) for colorimetry and spectrometry. This method is used by British ceramic research association (BCRA). Hence the mechanism of visual assessment of camouflage is more critical than pass/fail decision of solid colors. CIE color difference is an established method of color deviation between OB where luminance, hue and chroma are the contrast features of chromatic adaptation for variations of target OB. The chromatic adaptation of desert sand, urban grey and foliage green are experimented by CIE color parameters, the method cannot cover multidimensional angle [90]. CIE colorimetry is the mechanism of color matching and predicting the color difference between two stimuli for identification of physical color. The technique has limitation for actual color appearance between OB due to structural variation of object (camouflage textiles) and CB. Chromatic properties of camouflage formulated textiles, camouflage materials, DGTWSICB materials are mostly demonstrated by CIE trichromatic hue of RGB and CIE L*, a*, b* color coordinates. UV-Vis-NIR spectrophotometer cannot measure color directly; it measures the physical attributes of materials concerning its ATR of light. Digital camera or hyperspectral camera can be used to measure the chromatic appearance in a controlled optical environment of OB. Digital camera can be used for color measurement of OB when highly textured and printed materials cannot be measured by color measurement spectrophotometer. The light reflected from OB is passed through the lens, and imaging is captured through two-dimensional sensors covered with RGB color filters [35].

8.2 Hyperspectral versus CDRI assessment of target signature against CBs-DGTWSICB

Hyperspectral imaging is an improved and modified version of multispectral imaging used for target detection and defense surveillance in UV-Vis-NIR ranges. Captured target signature and CB in a hyperspectral image are difficult to characterize in terms of identification and quantification of concealment. Generally, target object (camouflage textiles) analysis of hyperspectral concealment needs to generate a spectral database of multidimensional CBs- DGTWSICB. Interfere elements of CDRI are not same for all CBs. These interferences need to be identified for all CBs for camouflage textiles. A standard spectral database identifies the discrimination of OB by means of spectrum probe. Spectral properties are controlled by scattering effects on OB. Treated camouflage textiles in UV-Vis-NIR are classified as supervised target detection of hyperspectral camera due to having known and predicted properties on textile substances. Target signature can be analyzed in terms of known CB for experimental process. Spectral angle, spectral distance and spectral information are the properties of spectral symmetry. To avoid interfering reflection of imaging, specification of target is very important for camouflage assessment of hyperspectral imaging. A simulation of spectral symmetry was conducted for typical signatures including CB materials such as: black brush, creosote leaves, sagebrush, red soil and dry grass. Reflection of interferer varies CB to CB. Spectral properties of DGTWSICB materials are not same. A real experimentation of hyperspectral camouflage textiles for spectral symmetry is required. Spectral symmetry and its analyses between target OB are existing techniques in prediction, simulation and planning stages only. Target signature versus CBs-DGTWSICB measurement of spectral similarity and dissimilarity of hyperspectral imaging are still challenging in optical engineering and unknown journey of camouflage researchers [20, 91, 92].

8.3 Mechanism of CDRI measurement for target signature against CBs-DGTWSICB

Pixel is another approach of camouflage signature evaluation for image segmentation and comparison of hyperspectral imaging between OB. The task is very challenging due to lacking of standardization for comparison of hyperspectral imaging [92]. Spectral imaging is a practicable technology for CDRI of target signature against CB. The signal of spectral imaging can provide a strong performance for analyses of optical properties of target object (camouflage textiles) and CB [93]. Spectral discrimination has been remarked as potential issue for day/night surveillance of military target. Performance of CDRI is achievable in terms of high band to band multispectral and hyperspectral sensors [94]. Electromagnetic optics, radiometry, photometry and human psychometrics are the technical areas for assessment of CDRI. It is necessary to develop an accurate process of concealment measurement for supporting of camouflage assessment. As summarized in Fig. 9, camouflage measurement on CB has been concerned about presumption, simulation, analysis and laboratory trialling, field experimentation and structural judgement, etc. Simulation and prediction represents the decision based on the predetermined process. Analysis and laboratory experiment includes quantitative and partial measurement for camouflage assessment. Field experimentation and structural judgement are the process of real game of concealment in multidimensional CBs-DGTWSICB [95, 96].

8.4 Image processing techniques for CDRI measurement against CBs-DGTWSICB

Every field experimentation for camouflage assessment is an expensive process. Natural illumination, target object, target CB and location of target OB are the real facts for every combat trialling of camouflage achievement [97]. Photograph of formulated textiles against CBs can be captured by digital camera/hyperspectral camera at specified angle and illumination for comparison between object (textile substances) and its surrounding CB. Lens changing of digital camera is an option for capturing photograph in different spectrums of UV-Vis-IR. The post image analyses are conducted by image processing software such as adobe photoshop, ImageJ, etc. Digital images can be modified into CIE-RGB color space to CIE L*, a*, b* color space under black-white grey scale of chromatic hue. CIE L*, a*, b* color space is defined between − 127 and + 127 for each axis of three-dimensional color space. 8 bits are suitable to interpret the color space. Color threshold is a chromatic & achromatic identification process functioned in ImageJ. This software covers CIE red, green, blue, L*, a*, b* color coordinates in black-white grey scale. The chromatic variation is a process applied for identification of camouflage textiles against multidimensional CBs-DGTWSICB. For example, fractal design (a typical percentage of CB is matched with textile object rather than matching whole object with background) is a common practice of defense professional for forest and desert camouflage in single background only. Recent research on camouflage textiles mostly limited to Vis range and chromatic assessment covers both quantitative and photographic systems. Hyperspectral camouflage textiles have a great limitation for right materials on textile substances for hyperspectral concealment and their quantitative and photographic/partial assessment process for camouflage textiles performance. Hyperspectral images in multidimensional CBs- DGTWSICB needs to generate an accurate view in specific lighting, angle and resolution for detection of camouflage properties on textile substances [5, 77, 98]. Color and intensity features of an image can signify the camouflage assessment and camouflage detection. Texture analysis with image processing is a very effective way of camouflage assessment for classification, segmentation and CDRI. Less intensity of an image depicts the appearance of dark camouflage and brighter intensity of an image creates the appearance of light camouflage [3, 22, 98, 99].

9 Advancement Phase-7, Significant Advancement Of Camouflage Textiles Against Modern Defense Surveillance In Uv-vis-nir Spectrums

Camouflage textiles does not mean camouflage clothing only. There are enormous concepts of applications of textile-based camouflage by means of spectrum probe in UV-Vis-NIR such as temporary combat residence, vehicle and location hiding, radar protection, missile protection, parachute protection, nuclear weapon and ballistic protection. Camouflage textiles for multidimensional single CB, simultaneous CB and adaptive CB need to be well established for defense protection. Recent research on camouflage textile is only intended to ‘CB color matching’ in terms of chromatic and patterning, but ‘color matching theory’ is only applicable for visible range while camouflage engineering is also required in UV-NIR ranges. Reflection angle of target signature changes the color appearance to the human observer/digital camera/hyperspectral camera. Surrounding environment colors of CB are not limited for any single CB. CB colors changes with location, season, foggy weather, sunny weather, rainy weather, bushfire of woodland, etc. Currently developed camouflage requirement concentrates on limited ranges of spectrum probe and minimum number of CB environments. Target objects are still detectable by the reflection of CB materials. Military camouflage textiles are already developed in Vis range and there is limitation of camouflage textiles in UV-NIR against multidimensional CBs-DGTWSICB. Furthermore, research on UV-Vis-NIR range camouflage textiles and the suitability of right camouflage materials for concealment are limited in published literature. High-performance camouflage textiles can be achieved by proper implementation of deceiving materials on textile substances. Conventional textile coloration process (coating, dyeing or printing) can be applied for treatment on textile substances with advance formulation of camouflage textiles. Existing camouflage textiles are not suitable for simultaneous camouflaging in UV-Vis-NIR ranges. There is a need for common textiles for camouflage in UV-Vis-NIR ranges. Temperature changing versus chromatic replacement or thermal changing versus chromatic stabilization created a demanding source of research and development in camouflage textiles for the protection of defense professional. The establishment of proposed technological advancement and right formulation of deceiving materials may generate an output of high-performance camouflage textiles in versatile single CB environment, adaptive camouflage for multidimensional CB environments, UV-Vis-IR camouflage, hyperspectral camera and radar protective camouflage for concealment of defense target signature.

9.1 Limitation of camouflage research, review and related findings

This review of camouflage textiles shows a limited number of research and publications in the specific area of high-performance camouflage textiles, but most research demonstrates prototype experimentation in a limited condition of individual research deficient with deeper concept of advanced analysis in UV-Vis-IR illumination against multidimensional CB materials-DGTWSICB, methodology and materials for camouflage formulation and right spectrometry for CDRI. Some patents have been published with lacking a concrete credential of material, methods and real testing process of camouflage formulation. The research and innovation in military camouflage might be a hidden activity of military scientist groups for keeping self-implementation of newly generated technology for any specific group and/or any country. Therefore, materials, methodologies, real testing methods of camouflage textiles are not being widely published. This review may opine a framework of right camouflage materials, methods and target illumination for designing advanced camouflage textiles under UV-Vis-IR surveillance.

10 Advancement Phase-8, Principle Of Optical Approach For Camouflage Textiles Coloration For Concealment Against Digital Camera Imaging/hyperspectral Imaging In Uv-vis-ir Spectrums

Camouflage coloration denotes altering the reflection of textile surface by means of technical coloration such as coating, dyeing and printing. Deceiving materials on textile substances are mainly termed as pigments, nano particles, dyes, eco-friendly source of natural materials, etc. Figure 10a and 10a1 shows the structural similarity of expected camouflage materials between OB when the target signature is depicted as zero reflection against CB, the human observer/digital camera/hyperspectral camera will not obtain a clear image of the real target for detection. Textile materials can be directly treated with CB source of natural materials such as natural plant-based natural dyes (NPND) and natural sand-based silicone dioxide (NSSD) for concealment against woodland, desertland, rockland, concreteland/urban and water/marine CBs [21, 100–106]. Figure 10b and 10b1, high light absorbency materials have been classified as low reflection materials. The reflection of target object will not be perceived for low reflection of object material. Therefore, minimum reflection of object materials has feasibility of camouflage coloration due to negligible response of photonic signal to remote sensing device such as digital imaging/hyperspectral imaging. Figure 10c and 10c1; similarly, the exact reflection of target signature will not be perceived by the human observer/digital camera/hyperspectral camera for high reflection materials. The photonic signal will be scattered to multidimensional direction without reaching the actual signal to the sensor of surveillance camera. Textile materials can be treated based on functional mechanism of high reflection materials such as selected nanoparticles, germanium, aluminium, titanium dioxide, etc. based on selected CB. Figure 10d and 10d1, the combination of reflection changing materials has the capability of altering reflection to the imaging device. In this optical principle, light will be reflected in different angle which can be twisted by reflection mechanism and misperception of image will be detected to signify target signature against CBs-DGTWSICB. For every UV-Vis-NIR surveillance, camera sensors of digital camera/hyperspectral camera generates imaging from photon signal of target signature and CB materials. Reflection and spectral signal of target signature (camouflage textiles) may alter photon signals for deceiving the target signature against CB. In thermochromic principle, chromatic replacement will occur in specific temperature range; the same camouflage textile is possible to implement in different CB environment in terms of chromatic matching in UV-Vis-IR spectrums. Thermal insulation is an opposite principle of chromatic phenomenon. Color will not change in specific temperature range; the same camouflage textile has the technical feasibility to use battlefield operation in different temperature in terms of chromatic matching and UV-Vis-IR camouflaging [15–17].

11 Advancement Phase-9, Hierarchical Model For Camouflage Textiles Formulation And Optical Assessment For Cdri-target Signature-dgtwsicb-uv-vis-ir

Figure 11 shows the standardized process of UV-Vis-IR camouflage textile formulation and performance measurement steps, which are segmented into nine categories for CDRI assessment of target signature against CBs- DGTWSICB and its surrounding environment.

Segment-1

Target CB selection is a primary attempt for camouflage coloration. Single CB or simultaneous CB or adaptive CB can be selected for target signature. DGTWSICB are the common CB area for technical formulation of camouflage textiles as per geographical combat- province of different country [18].

Segment-2

The deceiving materials need to be selected for concealment of specific CB environment. Reflection changing materials, reflection matching materials, thermochromic dyes, liquid crystal, crystal violet lactone, thermal insulation materials and CB source based NPND-NSSD materials are selected as the main deceiving materials for UV-Vis-IR camouflage textiles in multidimensional CB environments-DGTWSICB. Deceiving materials can be encapsulated by a transparent polymeric binder. Thermochromic and thermal insulation effects on chromatic stability and it's camouflaging performance can be tested under different temperature ranges [15–17, 107].

Segment-3

The suitability of deceiving materials treatment for camouflage textiles can be experimented by coating, dyeing and printing process of textile coloration. These techniques can be modified by the combination of coloration process to achieve camouflage in different CB environments-DGTWSICB such as dyeing and coating, printing and coating, etc.

Segment-4

The concealment properties of camouflage treated textiles against the selected materials of DGTWSICB can be identified in Vis and limited NIR ranges by color measurement spectrophotometer. Both specular included and excluded methods can be used for chromatic analysis of formulated textiles and combat materials. For illumination measurement of glossy materials, specular included option is the most suitable for capturing highest reflection in diffuse illumination. Furthermore, the structural properties of camouflage, chromatic compound identification and related chemometric analysis can be executed by scanning electron microscopy (SEM), Fourier transform infrared spectroscopy (FTIRs), UV-Vis-NIR spectrophotometer for laboratory stage trialling [108].

Segment-5

The evidence of target signature in UV-Vis-IR range surveillance can be implemented by digital camera. The digital camera can reveal the target signature against multidimensional CBs-DGTWSICB [109].

Segment-6

The captured photographs of digital camera can be analyzed by image processing software (ImageJ) for confirmation of CDRI under CIE red, green, blue, L*, a*, b* chromatic hue of black-white grey scale. The OB image can be segmented by color threshold method [22, 98].

Segment-7

Quantitative color differences of OB can be judged by CIE L*, a*, b*, c*, h values. Achromatic features of target signature and CBs, and their effects can also be identified for CDRI assessment. Hence, the chromatic and achromatic assessments of target signature versus DGTWSICB can be experimented by photographic illumination in UV-Vis-IR [17, 19, 22, 78, 109, 110].

Segment-8

Hyperspectral camera can be used for high-performance applications of camouflage assessment in UV-Vis-NIR ranges from 200 nm to 2500 nm [1, 12, 36].

Segment-9

Optical accuracy of spectral design for spectral symmetry, chromatic appearance and illumination properties can signify the CDRI of target signature against selected CB. The ATR properties of camouflage treated textiles and CB materials can be experimented in UV-Vis-NIR ranges from 200 nm to 2500 nm [1, 36, 111]. Target signature against DGTWSICB captured by hyperspectral camera can also be assessed by image processing software. Therefore, the chromatic aberration of multidimensional color and texture of target signature and CBs can be assessed for CDRI.

12 Concluding Remarks

ATR properties of formulated textile surface, ATR properties of selected CBs materials, chromatic appearance of digital/hyperspectral imaging, CIE trichromatic hue, structural features, sun radiation related to weather conditions, illumination angle, imaging sensors of digital camera/hyperspectral camera and electromagnetic spectrums in UV-Vis-IR are the key principle for every CDRI evaluation of target signature against CBs-DGTWSICB and its surrounding combat environments. Imaging signals of CDRI mostly depends on electron energy and photonic signal of target signature in UV-Vis-IR illumination. Camouflage textiles can be detected by human eyes (Vis) or instrumental investigations such as spectroscopy, microscopy, digital camera and hyperspectral camera. The reflectance profile of a target signature (camouflage textiles) can be matched with the reflectance profile of CB in the vein of chromatic, achromatic and spectral illumination. For chromatic matching between target object and CBs, selection of correct deceiving materials is a first task for camouflage textiles formulation. Hence, an appropriate treatment of deceiving materials on textile substances may signify the concealment of target signature in multidimensional CBs-DGTWSICB under UV-Vis-IR illumination. Camouflage materials can be treated on textile substances by the conventional technology of dyeing-coating-printing. The chromatic standardization of CB materials in laboratory stage has been opined for chromatic assessment of CB versus camouflage treated textiles. The core materials of CB and camouflage formulated textiles can be considered for CDRI assessment in laboratory stage as real CB materials have variation due to known and unknown interference in CB environments. These unknown parameters of CBs can be controlled sequentially if textile treated materials can be concealed/matched against CB materials under selected illumination in UV-Vis-IR spectrums, it may have core achievement for design of camouflage textiles. Therefore, target signature can be concealed under interference of CB environment and natural illumination in field trialling. Reflecting color of target signature and CB creates the imaging signal, rather than the absorbed color. White CB of natural environment reflects the entire wavelength of visible light. Other CB absorbs light at specific wavelength. Such as green leaves background of woodland CB reflects green color and absorbs other color; snow background of snowland CB reflects in full spectrum of visible wavelength. Electron energy of camouflage materials of target signature can replace the wavelength and imaging signal in digital/hyperspectral imaging. Textile substances can be treated with zero reflection materials, natural materials, CB source based natural materials such as NPND & NSSD, minimum/maximum reflection materials, multi-reflection materials for replacement/matching of electron energy against CBs and/or confusing the target signature. The electron energy of target signature generates energy of photon signal to be detected by imaging sensor and surveillance cameras. Therefore, the spectral signal of zero reflection/high reflection materials may create simultaneous camouflaging in UV-Vis-IR spectrums. Hyperspectral camera can be used for chromatic and spectral observation of CDRI using a wide proportion of electromagnetic spectrums in UV-Vis-NIR ranges. The concealment of latest surveillance in UV-Vis-NIR illumination can be premeditated by altering or symmetrization of surface reflection of target object with CB. The distance between the camera and target signature creates variation of photon signal. Positions of target object vibrates the velocity of electron energy and photonic signal to the imaging sensor. Reflection of target object, conditions of CB environment, single CB or simultaneous CBs, right selection of deceiving materials are the matter of altering the electron state/photon signal for accuracy of CDRI under UV-Vis-IR spectrums. Hence the advancement of camouflage textiles technology can be implemented for concealment of modern defense surveillance in UV-Vis-IR against multidimensional CBs-DGTWSICB. Furthermore, the principle of materials design versus optical engineering has outermost applications of camouflage weapon design against hyperspectral surveillance in UV-Vis-NIR spectrums. Camouflage product developer need to consider spectral signal for every high-performance concealment as upcoming surveillance is gradually vibrating towards more sophisticated to sophisticated. Table 2, in terms of review of optical hypothesis, author coalesced ‘42 possible formulations’ for advance design of camouflage textiles/CDRI trialling against multidimensional CBs-DGTWSICB in UV-Vis-IR illumination and expected outcomes (1–7) have been tabulated. In general, camouflage beads formation is proposed by microencapsulation with PU binder; and coating/dyeing/printing on polyamide 6,6 (PA 6,6) and/or other selected fabric required by defence professional for combat action of camouflaging.

Table 2

, Camouflage materials design, method design and testing formulations against multidimensional CBs-DGTWSICB

Total Trials (Ts)	**Expected Outcome-01: Design of woodland camouflage textiles/simultaneous background camouflage for concealment in UV-Vis-IR spectrums**			
	Trials	**Materials**	**Method**	**Lab/Field Testing**
T-01	Formulation-01	Chromium oxide	Deceiving beads formation by microencapsulation with PU binder and Coating/dyeing/printing/padding on PA 6,6 fabric/other selected fabric	Color measurement Spectrophotometer UV-Vis-NIR spectrophotometer SEM, FTIRs Digital Camera Hyperspectral Camera Image processing software
T-02	Formulation-02	Aluminium nano particle		
T-03	Formulation-03	Chromium oxide + Aluminium nano particle		
T-04	Formulation-04	Natural materials of woodland, NPND		
T-05	Formulation-05	Chromium oxide + CBP		
T-06	Formulation-06	Selected synthetic Dyes and its technical formulation		
	Expected Outcome-02: Design of desert camouflage textiles/simultaneous background camouflage for concealment in UV-Vis-IR spectrums			
T-07	Formulation-01	Mica powder	Deceiving beads formation by microencapsulation with PU binder and Coating/dyeing/printing/padding on PA 6,6 fabric/other selected fabric	Color measurement Spectrophotometer UV-Vis-NIR spectrophotometer SEM, FTIRs Digital Camera Hyperspectral Camera Image processing software
T-08	Formulation-02	Titanium dioxide + Aluminium nano particle		
T-09	Formulation-03	Mica powder + Aluminium nano particle		
T-10	Formulation-04	Natural materials of desertland, NSSD		
T-11	Formulation-05	Selected acid Dyes		
T-12	Formulation-06	Mica powder + CBP		

Total Trials (Ts)	**Expected Outcome-01: Design of woodland camouflage textiles/simultaneous background camouflage for concealment in UV-Vis-IR spectrums**			
	Trials	**Materials**	**Method**	**Lab/Field Testing**
	Expected Outcome-03: Design of water/marine camouflage textiles/simultaneous background camouflage for concealment in UV-Vis-IR spectrums			
T-13	Formulation-01	Titanium dioxide	Deceiving beads formation by microencapsulation with PU binder and Coating/dyeing/printing/padding on PA 6,6 fabric/other selected fabric	Color measurement Spectrophotometer UV-Vis-NIR spectrophotometer SEM, FTIRs Digital Camera Hyperspectral Camera Image processing software
T-14	Formulation-02	Germanium nano particle		
T-15	Formulation-03	Titanium dioxide + Germanium nano particle		
T-16	Formulation-04	Titanium dioxide + CBP		
T-17	Formulation-05	Selected synthetic Dyes and its technical formulation		
T-18	Formulation-06	CBP + Germanium nano particle		
	Expected Outcome-04: Design of snowland/sky camouflage textiles/simultaneous background camouflage for concealment in UV-Vis-IR spectrums			
T-19	Formulation-01	Lead oxide	Deceiving beads formation by microencapsulation with PU binder and Coating/dyeing/printing/padding on PA 6,6 fabric/other selected fabric	Color measurement Spectrophotometer UV-Vis-NIR spectrophotometer SEM, FTIRs Digital Camera Hyperspectral Camera Image processing software
T-20	Formulation-02	Titanium dioxide		
T-21	Formulation-03	Germanium nano particle		
T-22	Formulation-04	Lead oxide + Germanium nano particle		
T-23	Formulation-05	Titanium dioxide + Germanium nano particle		
T-24	Formulation-06	Selected synthetic Dyes and its technical formulation		

Total Trials (Ts)	**Expected Outcome-01: Design of woodland camouflage textiles/simultaneous background camouflage for concealment in UV-Vis-IR spectrums**			
	Trials	**Materials**	**Method**	**Lab/Field Testing**
T-25	Formulation-07	Titanium dioxide + CBP		
	Expected Outcome-05: Design of iceland camouflage textiles/simultaneous background camouflage for concealment in UV-Vis-IR spectrums			
T-26	Formulation-01	Zinc oxide	Deceiving beads formation by microencapsulation with PU binder and Coating/dyeing/printing/padding on PA 6,6 fabric/other selected fabric	Color measurement Spectrophotometer UV-Vis-NIR spectrophotometer SEM, FTIRs Digital Camera Hyperspectral Camera Image processing software
T-27	Formulation-02	Titanium dioxide		
T-28	Formulation-03	Germanium nano particle		
T-29	Formulation-04	Zinc oxide + Germanium nano particle		
T-30	Formulation-05	Titanium dioxide + Germanium nano particle		
T-31	Formulation-06	Selected synthetic Dyes and its technical formulation		
T-32	Formulation-07	Titanium dioxide + CBP		
	Expected Outcome-06: Design of stoneland/concreteland/urban camouflage textiles/simultaneous background camouflage for concealment in UV-Vis-IR spectrums			
T-33	Formulation-01	Natural materials of stoneland	Deceiving beads formation by microencapsulation with PU binder and Coating/dyeing/printing/padding on PA 6,6 fabric/other selected fabric	Color measurement Spectrophotometer UV-Vis-NIR spectrophotometer SEM, FTIRs Digital Camera Hyperspectral Camera Image processing software
T-34	Formulation-02	Germanium nano particle		
T-35	Formulation-03	Pumic Powder + Germanium nano particle		
T-36	Formulation-04	Selected synthetic Dyes and its technical formulation		

Total Trials (Ts)	**Expected Outcome-01: Design of woodland camouflage textiles/simultaneous background camouflage for concealment in UV-Vis-IR spectrums**			
	Trials	**Materials**	**Method**	**Lab/Field Testing**
T-37	Formulation-05	Pumic Powder + CBP		
	Expected Outcome-07: Design of temperature adaptive camouflage textiles for concealment in UV-Vis-IR spectrums			
T-38	Formulation-01	Thermochromic leuco dyes + liquid crystal	Deceiving beads formation by microencapsulation with PU binder and Coating/dyeing/printing/padding on PA 6,6 fabric/other selected fabric	Color measurement Spectrophotometer UV-Vis-NIR spectrophotometer SEM, FTIRs Digital Camera Hyperspectral Camera Image processing software
T-39	Formulation-02	Thermochromic leuco dyes + PCM		
T-40	Formulation-03	Thermochromic leuco dyes + PCM + Liquid crystal		
T-41	Formulation-04	Selected synthetic Dyes and its technical formulation		
T-42	Formulation-05	Thermochromic leuco dyes + PCM + Liquid crystal + Germanium		

Abbreviations And Glossaries For Camouflage Experimentation

UV-Vis-IR: ultraviolet-visible-infrared; **DGTWSICB:** dry leaves, green leaves, tree bark-woodland combat background; water-marine combat background; sand-desertland combat background; stone-stoneland combat background; snow-snowland combat background; sky combat background; ice-iceland combat background and concrete-concreteland combat background; **CBs:** combat backgrounds; **CDRI:** concealment, detection, recognition and identification; **NIR:** near infrared; **nm:** nanometer; **Target signature:** camouflage textiles for concealment and detection; **Woodland combat background:** camouflaging and detection of target signature in woodland background such as: dry leaves, green leaves, tree bark, etc.; **water/marine combat background:** camouflaging and detection of target signature in water/marine background; **Desertland combat background:** camouflaging and detection of target signature in desertland background; **Stoneland combat background:** camouflaging and detection of target signature in stoneland background; **Snowland combat background:** camouflaging and detection of target signature in snowland background; **Sky combat background:** camouflaging and detection of target signature in sky background; **Iceland combat background:** camouflaging and detection of target signature in iceland background; **Concreteland/urban combat background:** camouflaging and detection of target signature in concreteland background; **Single background camouflage:** camouflaging and detection of target signature in specific background environment-DGTWSICB; **Simultaneous background camouflage:** camouflaging and detection of target signature in few background environments-DGTWSICB; **Adaptive camouflage:** camouflaging and detection of target signature in few background environments-DGTWSICB; **Temperature adaptive camouflage:** camouflaging and detection of target signature in temperature changing environments against few background-DGTWSICB; **NPND:** natural plant-based natural dyes; **NSSD:** natural sand-based silicon dioxide; **PCMs:** phase change materials; **CBP:** carbon black pigment; **SEM:** scanning electron microscopy, **FTIRs:** Fourier transform infrared spectroscopy; **PU:** polyurethane; **PA 6,6:** polyamide 6,6; **CIE:** International Commission on Illumination; **RGB:** red, green, blue. **OB:** object-background

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Figures

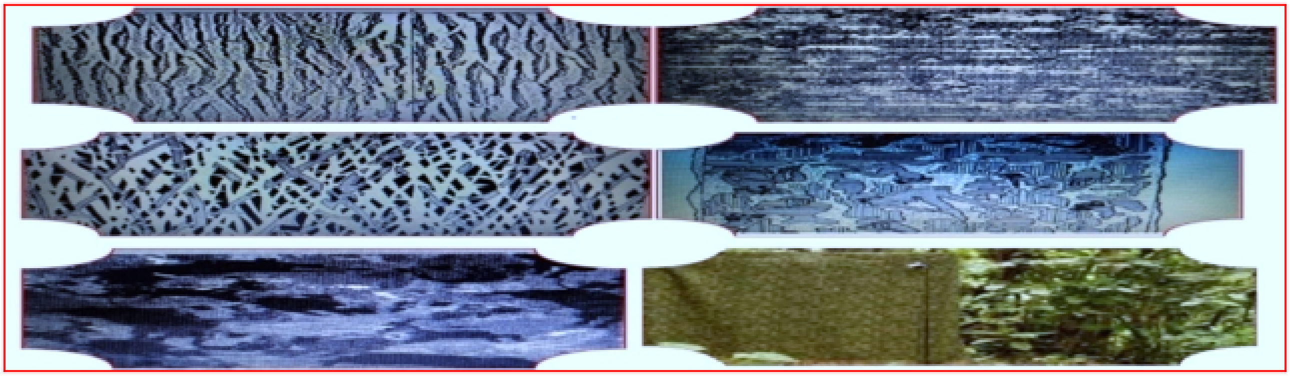


Figure 1

Camouflage textile patented and designed for single CB environment and limited spectrum probe.

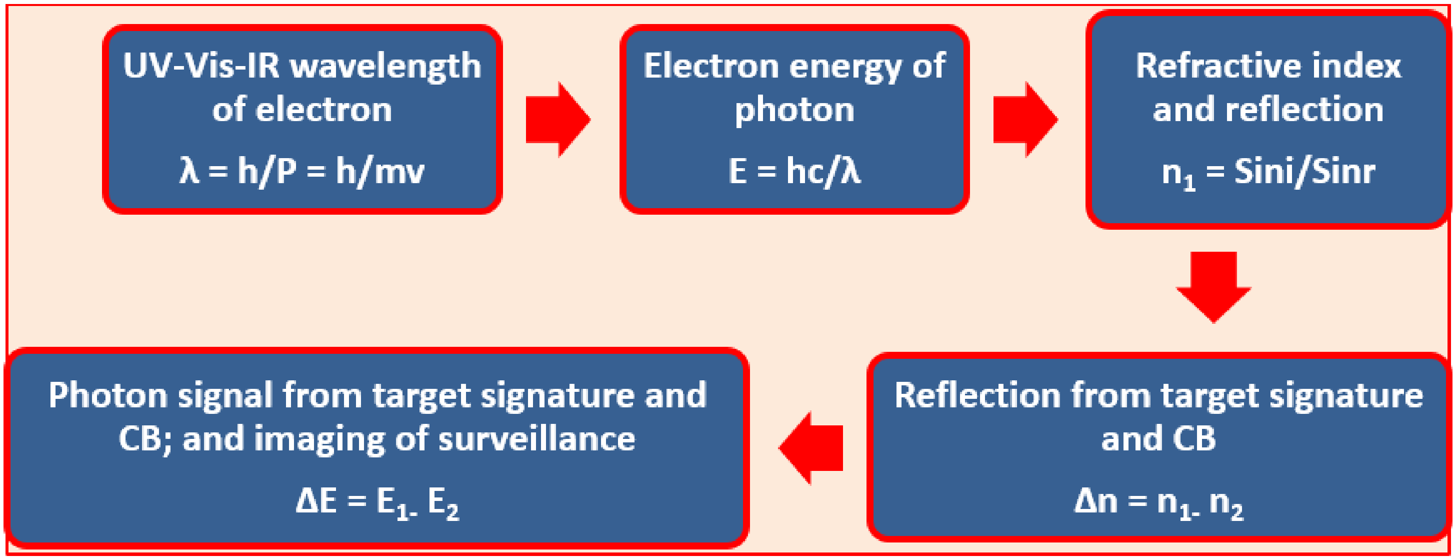


Figure 2

Illumination principle of digital camera imaging-hyperspectral camera imaging-UV-Vis-IR- CDRI for defence target signature against CBs- DGTWSICB

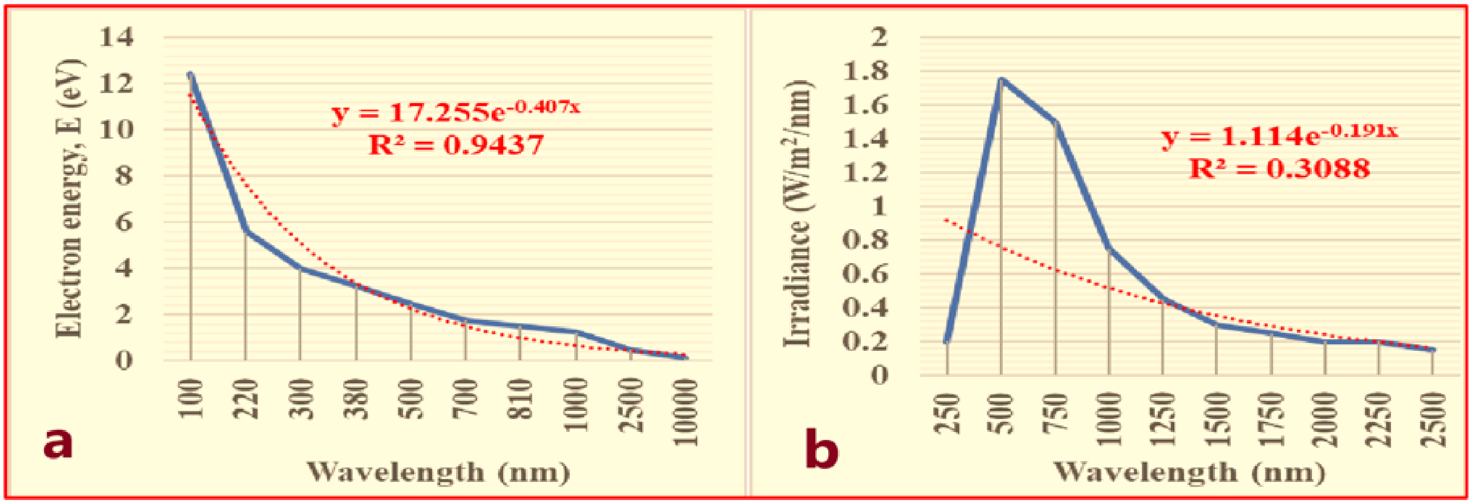


Figure 3

An exponential relationship of wavelength versus electron energy, 100-10000 nm (a) and sun radiation, 250-2500 nm (b) in UV-Vis-IR spectrums.

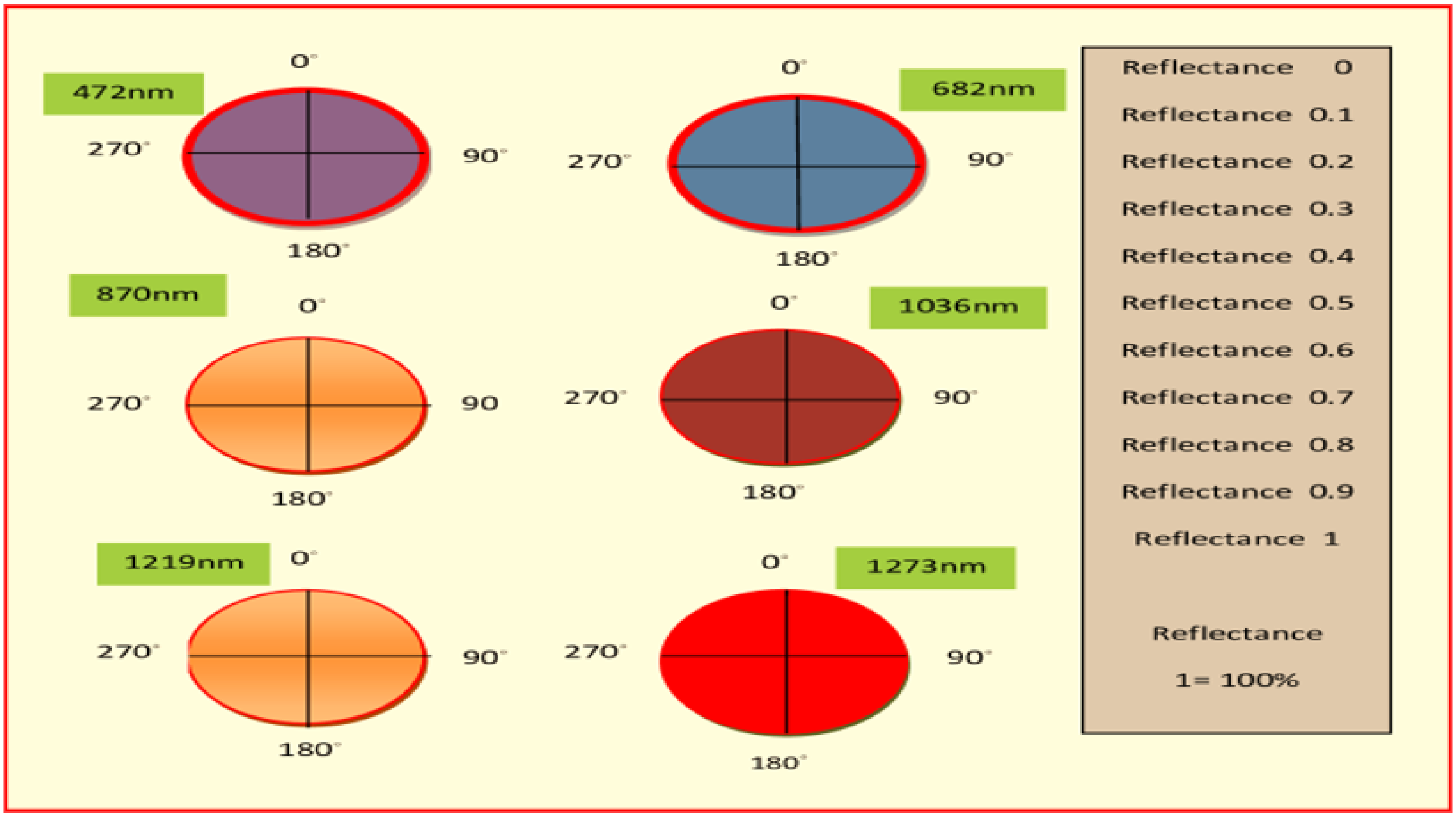
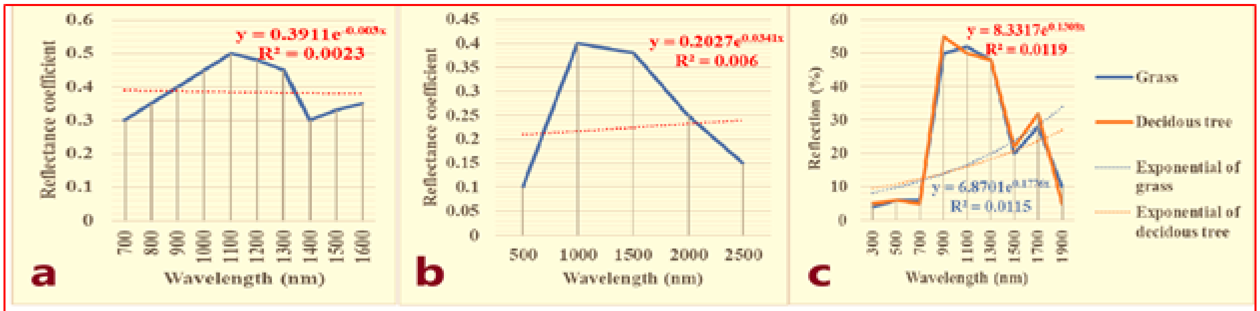
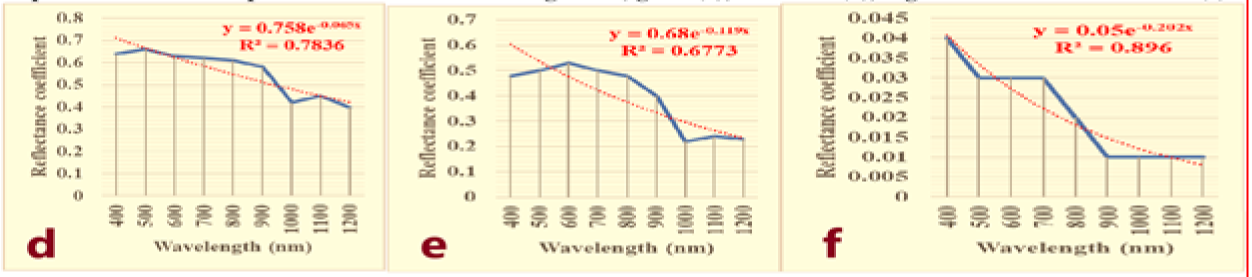


Figure 4

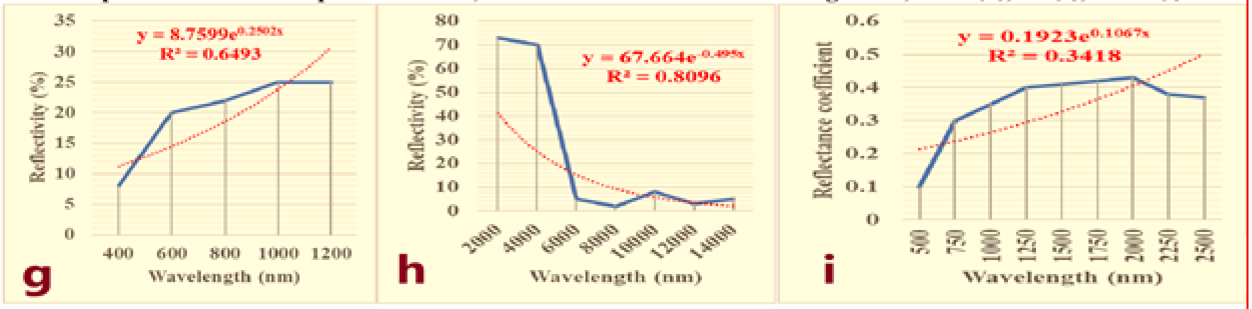
Chromatic appearance (schematic) of six specified wavelength (nm) in Vis (472 nm and 682 nm) and NIR (870 nm, 1036 nm, 1219 nm and 1273 nm) spectrums.



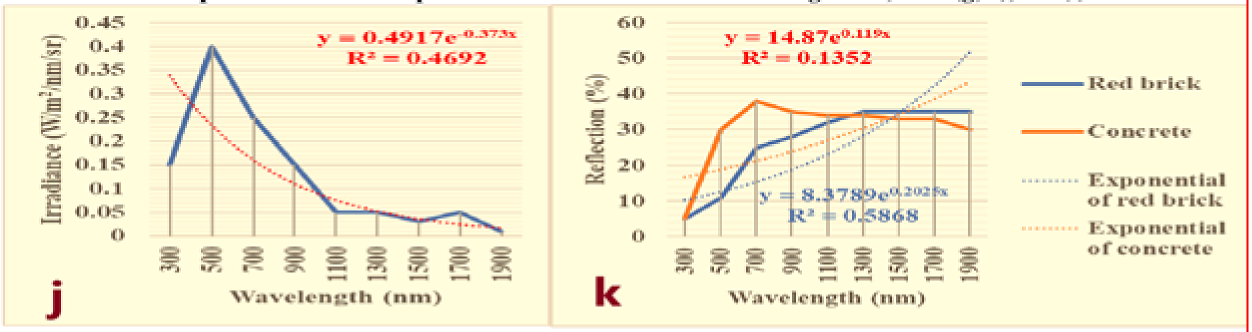
Exponential relationships of woodland combat background; grass (a), tree bark (b), vegetation and deciduous tree (c).



Exponential relationships of snowland, iceland and marine combat background; snow (d), ice (e), water (f).



Exponential relationships of desertland and soil combat background; sand (g, h), soil (i).



Exponential relationships of sky and urban combat background; sky (j), red brick and concrete (k).

Figure 5

Exponential relationship of multidimensional CBs-DGTWSICB materials in UV-Vis-IR spectrums; a, 700-1600 nm; b, 500-2500 nm; c, 300-1900 nm; d, 400-1200 nm; e, 400-1200 nm; f, 400-1200 nm; g, 400-1200 nm; h, 2000-14000 nm; i, 500-2500 nm; j, 300-1900 nm; k, 300-1900 nm.

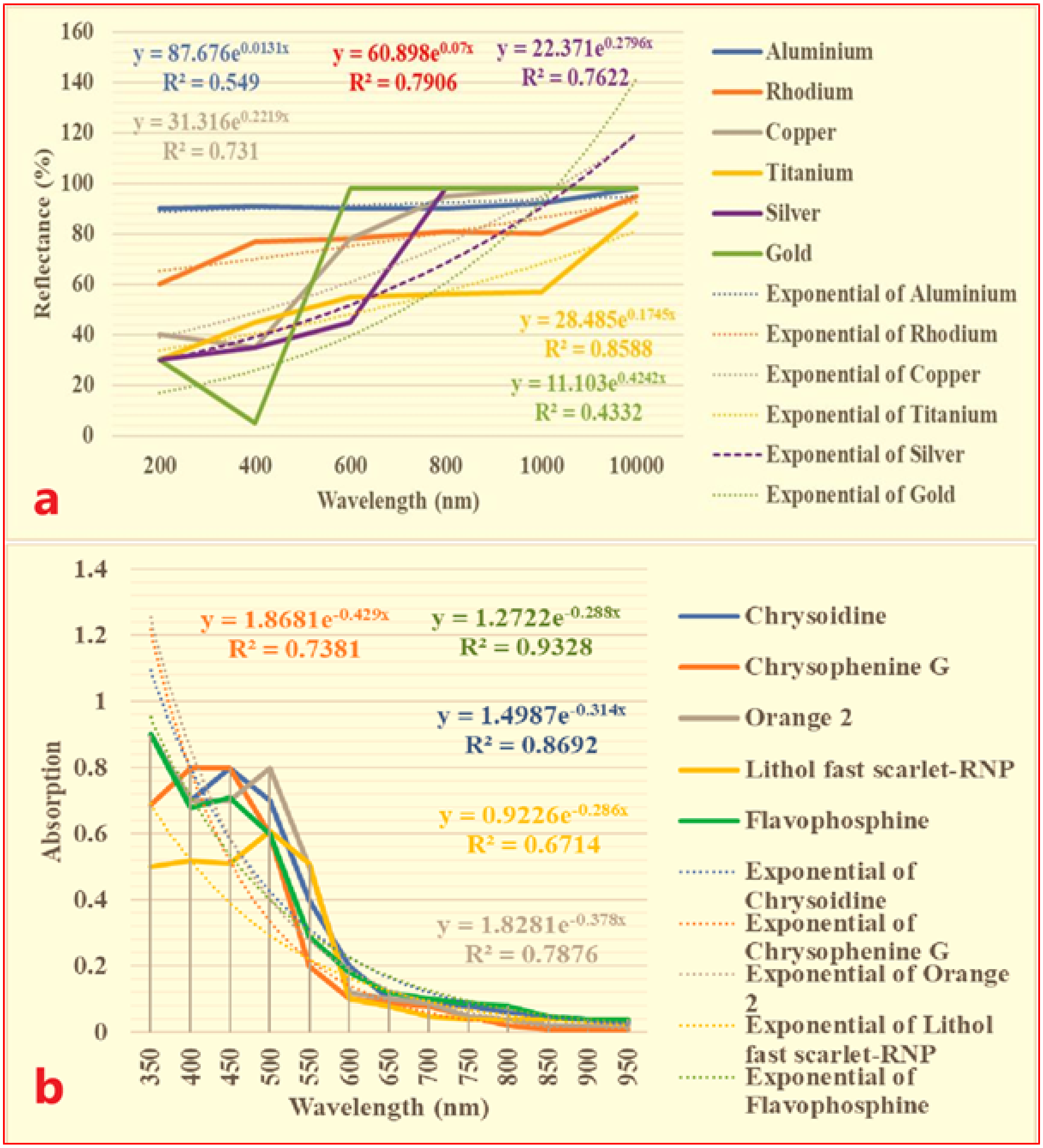


Figure 6

Spectral signals of high reflection materials at 200-10000 nm (a) and synthetic dyes at 350-950 nm (b) in UV-Vis-IR spectrums with the relationship of exponential coefficients.

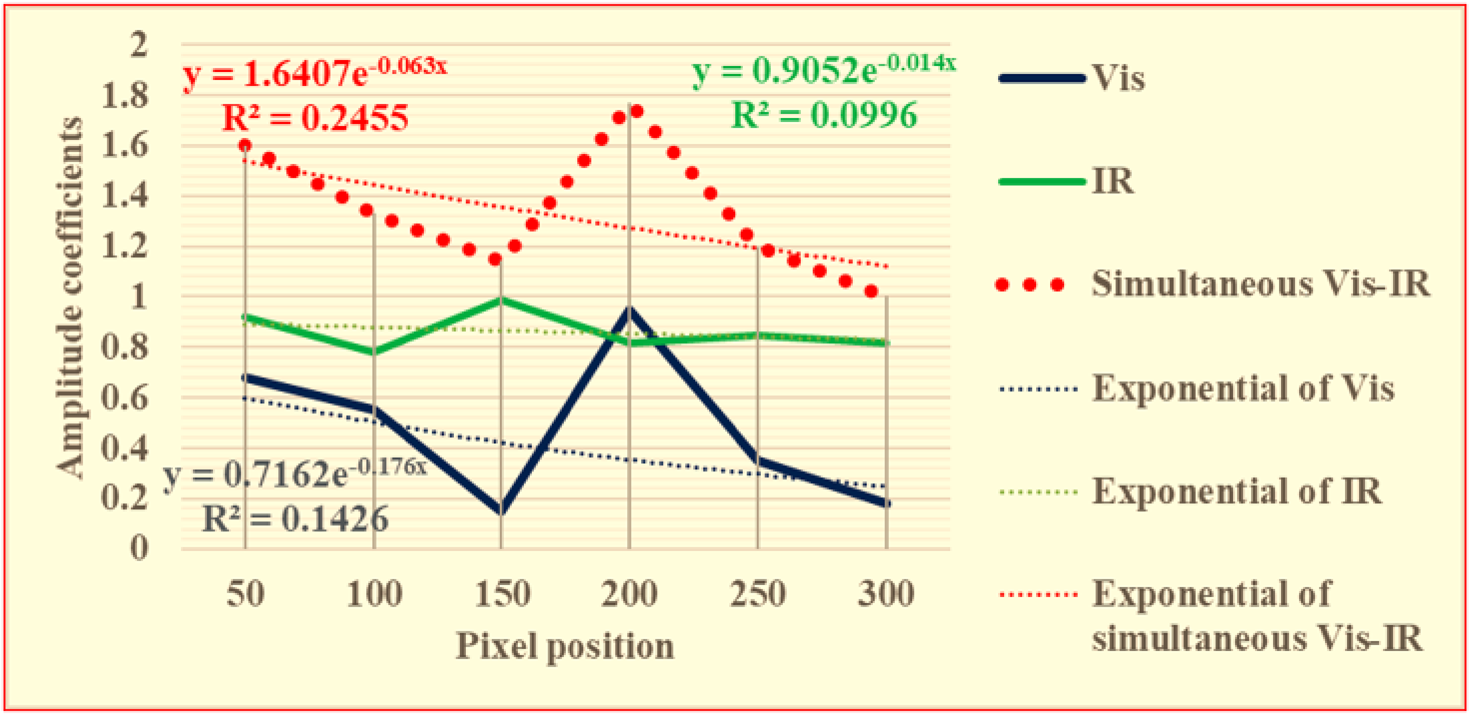


Figure 7

Exponential of Vis-IR photonic signal versus design of camouflage materials for simultaneous spectrum probe.

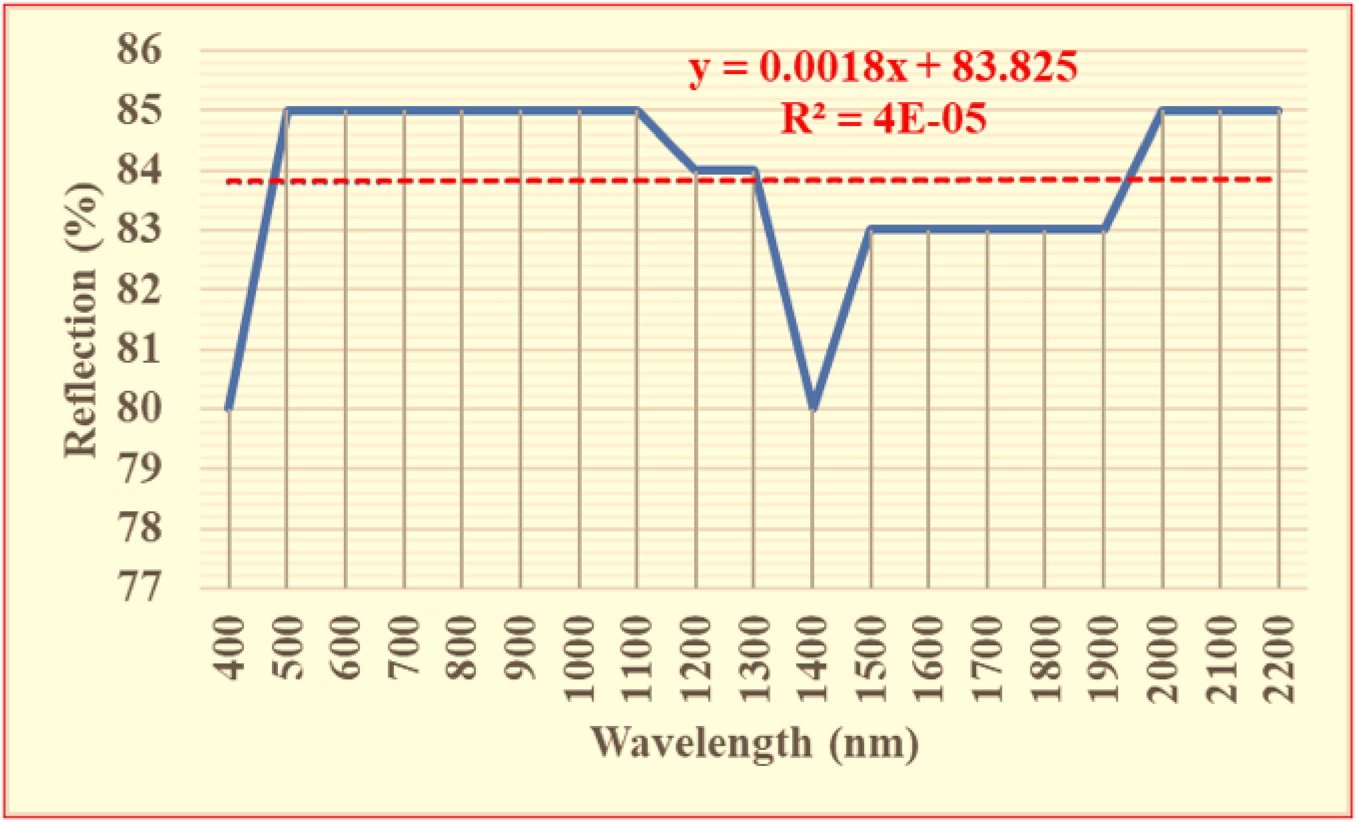


Figure 8

Exponential spectra of ZnO pigment in Vis-NIR from 400 nm to 2200 nm.

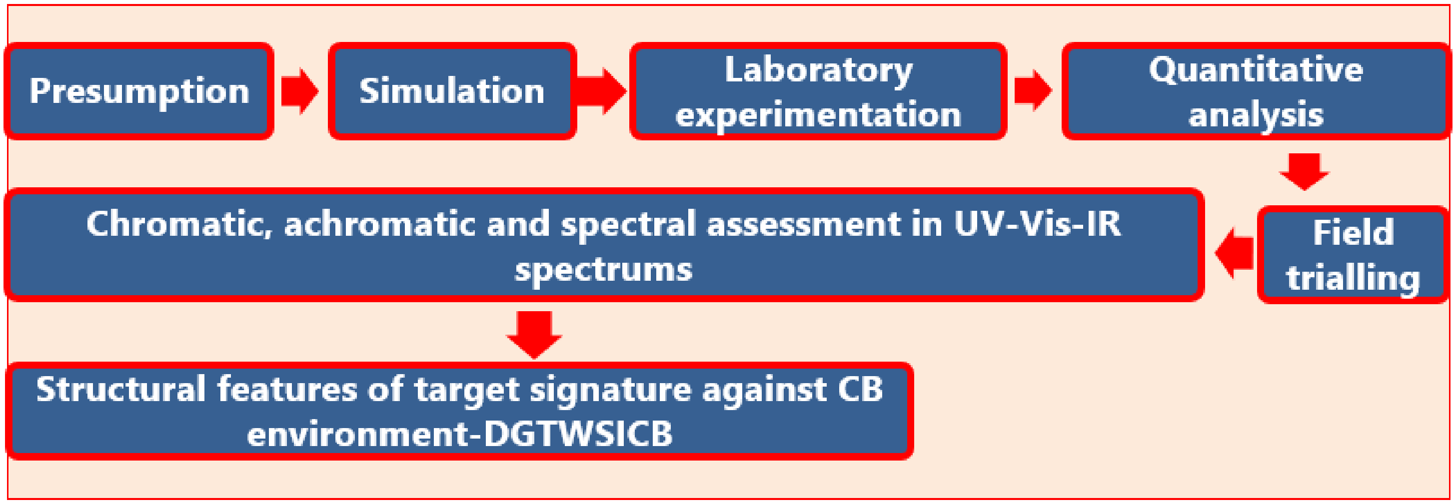


Figure 9

Flow chart for principle of camouflage assessment.

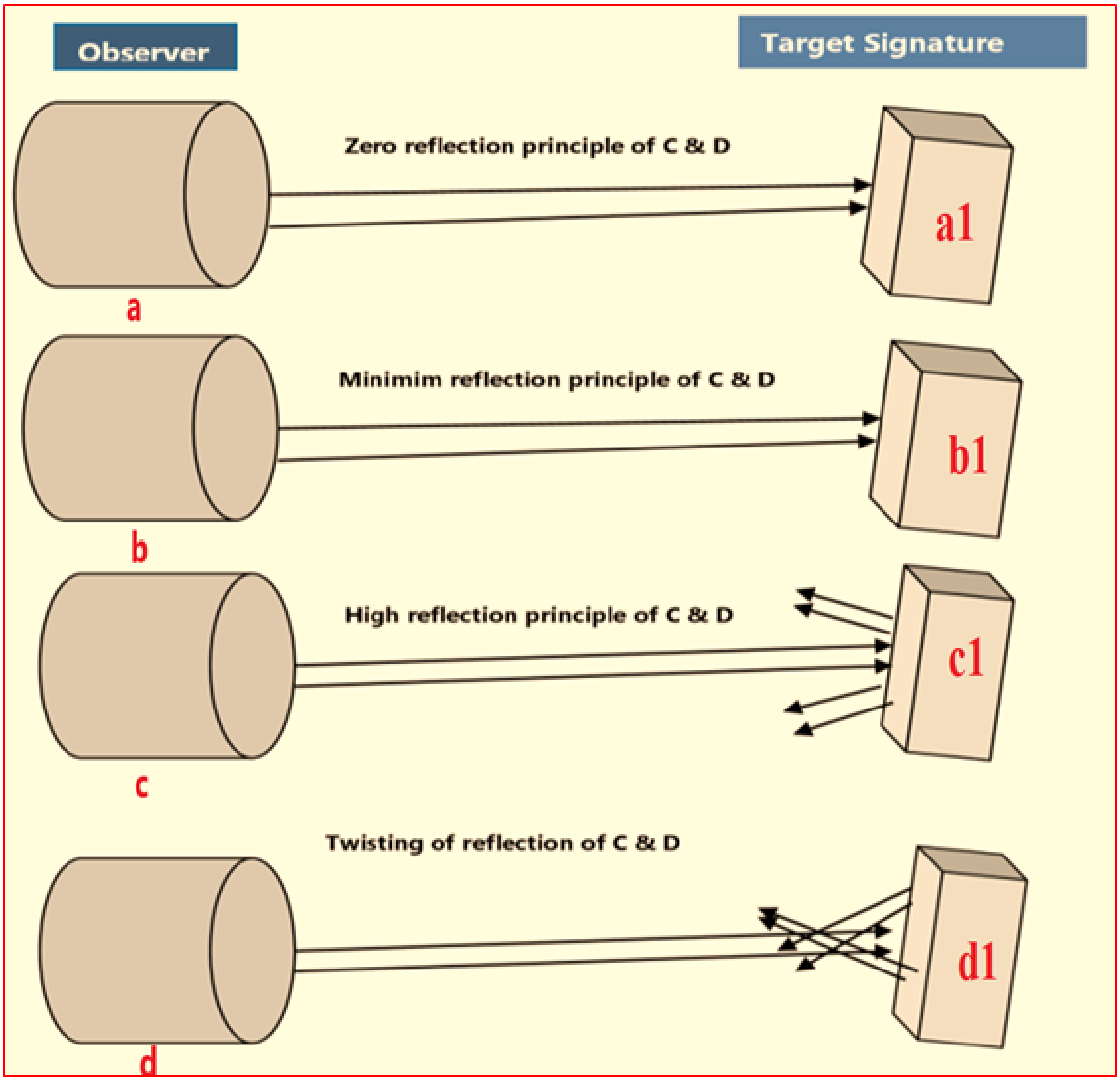


Figure 10

Optical principle of concealment and detection (C & D) between observer (a, b, c, d) and target signature (a1, b1, c1, d1) against multidimensional CBs-DGTWSICB

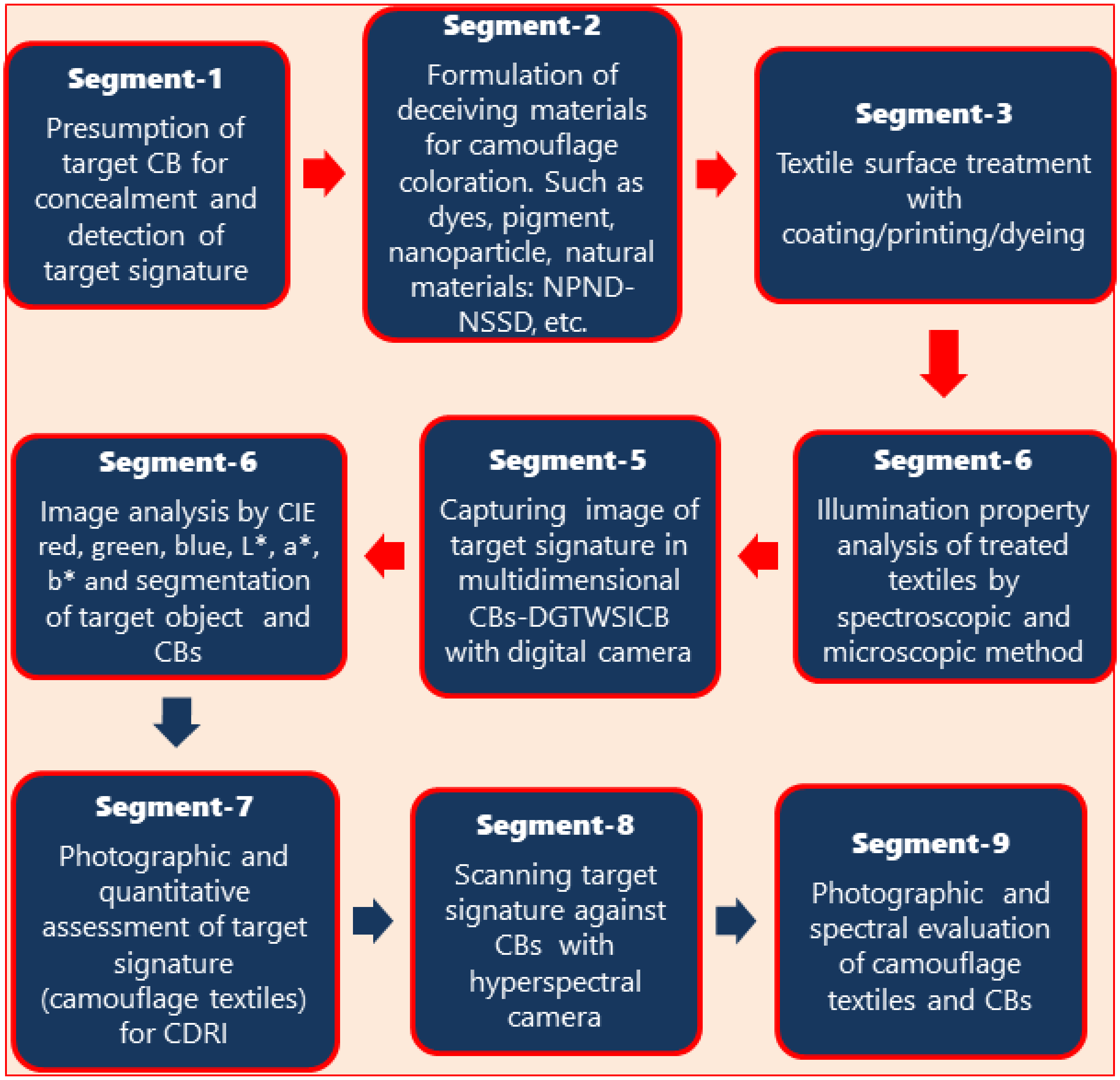


Figure 11

Flow chart of technical formulation for design of camouflage textiles against DGTWSICB and optical assessment for CDRI in UV-Vis-IR imaging

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