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Thermal Camouflage Clothing in Diurnal and Nocturnal Environments

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Abstract. This paper shows the possibility to thermally camouflage a human body in a beach environment, during the day and at night, through the use of two knitted fabric clothing prototypes. The conceptual design process applied was initially developed based on the need to firstly understand the behaviour of an individual dressed under the focus of a thermal imaging camera in the light of the infrared spectrum. The thermal tests undertaken to observe the model's thermal camouflage in certain positions/perspectives in both environments, enable simultaneously running of different solutions while introducing changes to the clothing. Printing with copper pigments and the patchwork using stitched structures in polyester knitted fabric played a decisive role to capture the thermal colours of the thermal image intended for the camouflage effect.

Introduction

In a modern war scenario, where the capture of spectral infrared images becomes a reality, clothing camouflage plays a decisive role in the soldier protection [1]. In thermal camouflage, the thermal difference between the target and the environment is associated with the atmospheric effect [2]. Clothing is thus involved in energy transfers, triggered between environment-clothing-body, where the emissivity and the temperature of the surface are interconnected with radiation [3]. The air and the subsequent movement (derived from the interactions between textile-skin-environment) can also interfere with the dynamics of the clothing depending on the composition of the textile material, the design applied to the clothing, as well as the movement triggered by the user [4].

The quest to reduce the thermal signature, is equivalent to the reduction of the emissivity and to the implementation of a single colour in thermal image to be applied in thermal camouflage clothing. An example of this is observed by a thermal imaging camera, in an outfit with the use of metallic materials, on the human body [5] such as a small sample with use of materials with physical properties which exceed those observed in nature, the metamaterials, on the hand of a human body [6].

In addition to the perspective of thermal signature cloaking of a certain object with the use of metamaterials [7, 8], is also evident the attempt of thermal signature metamorphosis, through the creation of other “ghost” targets, external to the real position of the thermal object/target which intended to camouflage, in order to create illusions in thermal vision [9, 10, 11, 12].

The use of thermochromic and electrochromic materials is also related to the achievement of a thermal camouflage with chameleonic character in the electromagnetic spectrum, associating the possibility of changing the behaviour of colour at the time of demand of the military [13, 14]. Recent approaches to the theme of thermal camouflage are also revealed in the development of active thermal surfaces, with electrical control of thermal emission, which allows the reduction of the emissivity, the change of colour and the creation of messages in thermal image [15], such as the development of nanophotonic structures that enable the control of the thermal signature of objects, in order to adapt them to clothing in the future [16].

The main goal of this work refers to the analysis and observation in thermal vision of the human body, previously idealized and dressed with three types of outfits, in an outdoor environment, diurnal and nocturnal, in order to understand the capture of the camouflage in thermal vision, according to the literature studied.

Therefore, tests will be performed with a human figure dressed in an outfit that can obtain camouflage in diurnal environment, a human figure dressed in an outfit that can obtain camouflage in nocturnal environment, and also with a human figure dressed in an outfit that does not have that ability. Both outfits were idealized in knitted fabric, tight to the body, to obtain a greater adaptability to body of textile structure and provide a greater stability of the body temperature behaviour in thermal image.

Materials and Methods

The previous study of several elements which involve a thermal camouflage environment (such as the behaviour of the skin and human body temperature, of the surrounding environment, of the clothing/textile material and of the colour of thermal image) were decisive for performing of the thermal tests with outfits with thermal camouflage functionality. So, the environment and the different moments of the thermal camouflage day, such as the human body, the textile material and clothing design, present in the thermal tests of this paper, emerged from previous studies (captured in outdoor and laboratorial environment), within the scope of doctoral thesis in fashion design [17, 18]. In addition to the thermal camouflage diurnal and nocturnal outfits, a plain thermal camouflage outfit was also conceptualized, with inspiration in the camouflage outfits design, in a single white cotton knitted fabric, very thigh to the body, in order to enable the observation of contrasts between the human body, the environment and the other outfits that obtain the thermal camouflage.

For the diurnal and nocturnal thermal tests a Testo 855 thermal imaging camera was used (Fig. 1 a), with the measuring option of -30 °C to 100 °C activated, between 7,5-14µm and emissivity adjustment of 0,95 (approximate value of the skin's emissivity). In the reproduction of thermal images and video was selected the "Iron" colour range, where the "black" colour relates to the lowest temperature (colder) and the "white" colour to the highest temperature (warmer). The simultaneous capture of the real and thermal video was possible through the use and connection of a Lumix GH5 camera with a Lumix 14-140 mm lens (Fig. 1 b) under the thermal imaging camera, assisted by a Bilora 936 tripod (Fig. 1 c). Moreover, the realization of the thermal video was assisted by the simultaneous use of Asus ROG Strix GL553V Laptop and Testo software. In the nocturnal tests, Aputure Amaran al-h198c camera LED light CRI95+3200-5500k was also used to enable the observation of the model's body movements. In order to measure the relative humidity and the atmospheric temperature values present in the selected outdoor environment for thermal camouflage, it was necessary the use of a thermohygrometer HANNA HI9564 (Fig. 1 d).

a) b) c) d)

Fig. 1 Photographs of the equipment: a) Testo thermal imaging camera; b) Lumix video camera; c) Bilora tripod; d) Thermohygrometer.

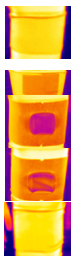
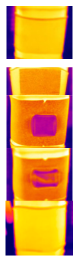
The behaviour of the human body dressed with the diurnal and nocturnal thermal camouflage outfits, such as with the plain of camouflage outfit was captured in the previously idealized place, on Carreço beach (located in Viana do Castelo, Portugal) through a female model, 1,80 m tall and measurements corresponding to the standard clothing size 36. At this point there was a concern to obtain the identical atmosphere conditions to the previous studies related to the tests performed in the outdoor and in the laboratory, such as the behaviour of the tide present in the thermal camouflage environment idealized, the low tide (through the consultation on the website https://tabuademares.com).

The thermal images/thermal video were capture on July 22nd, 2018, during the day, between 5.30 pm to 8.30 pm and at night, from 11.20 pm until 00.30 am on the 23rd, with clear sky and light wind in both times of the day. The values of atmospheric temperatures and relative humidity oscillated slightly between the temporal space of thermal tests, namely: i) in diurnal thermal tests: between 23,8 ºC and 27 ºC temperature atmospheric values and between 52,1 % and 67,2 % relative humidity values; and ii) in nocturnal thermal tests: between 20,5 °C and 17,1 ºC temperature atmospheric values and between 71,3 % and 90,4 % relative humidity values. The need to study the best form of camouflage as well as an unforeseen situation with computer battery allowed the diurnal thermal test to be more time-consuming compared to the nocturnal test.

Results

The characteristics of the materials used in the previous study in laboratory environment [17, 18] are shown in Table 1, being relevant for the elaboration of the outfits tested in an outdoor environment, at day and night.

Table 1 Textile materials and selected techniques, adapted from the paper [18].

Sample	Photography	Thermal Image 24 ºC	Thermal Image 18 ºC	Emissivity [ε]
A4*				0,76
A4*1				0,50
A4*2				
A4*3				
A5*4				0, 82

* Knitted fabric: Jersey 100% Polyester; 153,39 g/m^2; 0,42 mm; 26,9 Tex; 15 wales/cm; 20 courses/cm

*1 with printed copper pigment (80 g Hydra Clear for Metallic with 20 g Cooper Powder)

*2 with application of sewing technique and interlining in the totality of the quadrangular form

*3 with application of sewing technique and interlining only on its side fitting

*4 Knitted fabric: Jersey 100% Cotton; 154,14 g/m^2; 0,42 mm; 19,6 Tex; 16 wales/cm; 21 courses/cm

Therefore, analysing the results of the colours obtained thermally in the selected materials, the elaboration of the two thermal camouflage outfits was proceeded, one for the diurnal environment and another for the nocturnal environment, as shown in Figs. 2 and 3. Through the use of the thermal imaging camera (in the "Iron" range) and the human figure, it is possible to observe, in some of the model's positions/perspectives, the harmony of the colours idealized in the outfits' design in thermal image, from the characteristics of the materials, pigments and applied techniques: i) in the diurnal outfit the yellow colour (A4*), in the white polyester knitted fabric, the orange colour (A4*1/A4*3) in the printed knitted fabric with copper pigment and in the embossed structure with partially fusible interlining and the magenta colour (A4*2/A4*3) in both knitted fabric with embossed structures; and ii) in the nocturnal outfit the magenta colour (A4*2/A4*3) in both knitted fabric with embossed structures and the orange colour (A4*1/A4*3) in the printed knitted fabric with copper pigment and in the embossed structure with partially fusible interlining.

The movement of the model boosts instability in the design and behaviour of the colours of the materials in thermal image. In parallel, the appearance of other colours in the materials and selected techniques is also noticeable, namely: orange and magenta ($A4^{*}$) in the white polyester knitted fabric; yellow, magenta and blue ($A4^{*1}$) in the printed knitted fabric with copper pigment; and blue ($A4^{*2}/A4^{*3}$) in the areas with knitted fabric embossed structures. The embossed structures' techniques (with fully and partially fusible interlining) did not show great among themselves in terms of colour behaviour in thermal image. In some moments, it is still possible to observe the yellow colour outlining areas of the model's silhouette in motion, especially at night, derived from different interactions between the environment, the clothing and the body.

In both environments (diurnal and nocturnal), the slow movement of the model (similar to a chameleon) and its position in front of rocky areas (in a background with more textures, patterns, irregularities and colours in thermal vision), provides an increase in the thermal camouflage functionality of the conceptualized outfits. In the situations in which the background was absent from this dynamism of the textures/patterns and colours the thermal camouflage functionality decreases, providing a greater exposure of the model's silhouette and clothing.

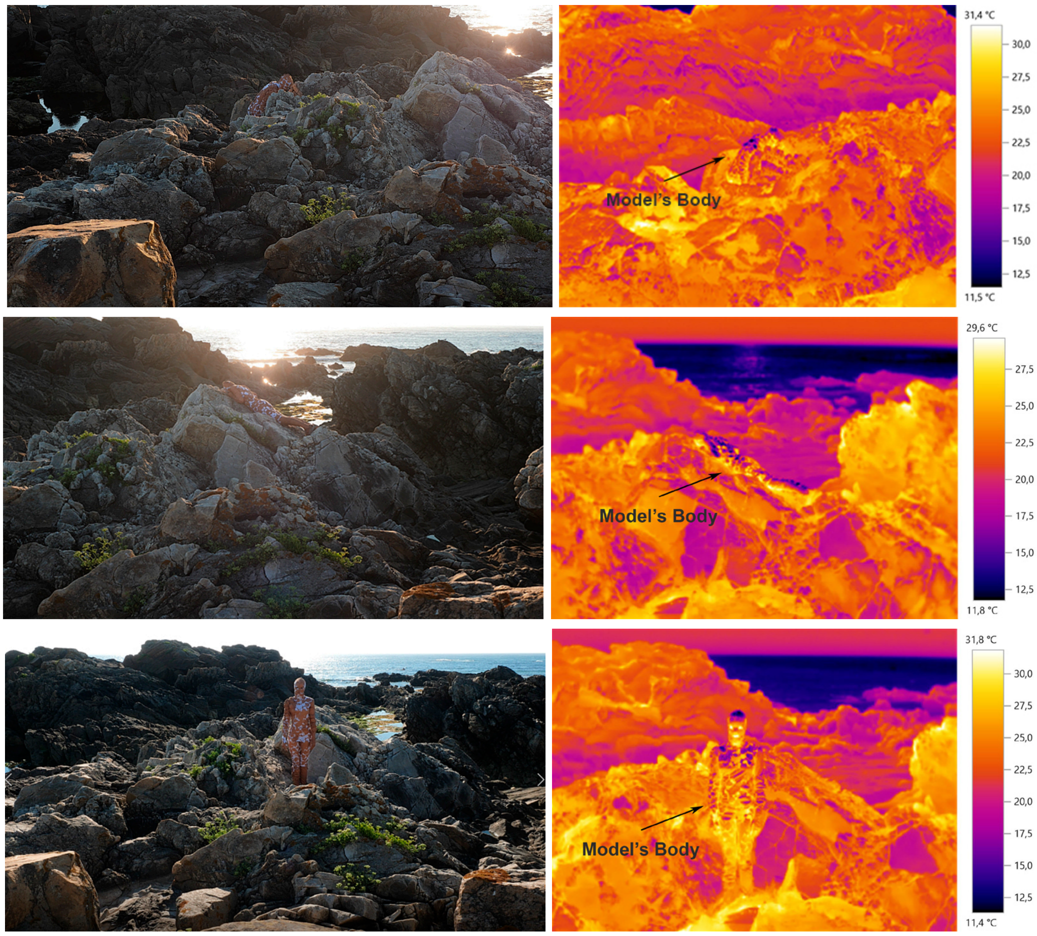


Fig. 2 The conceptualized thermal camouflage outfit for the diurnal environment.

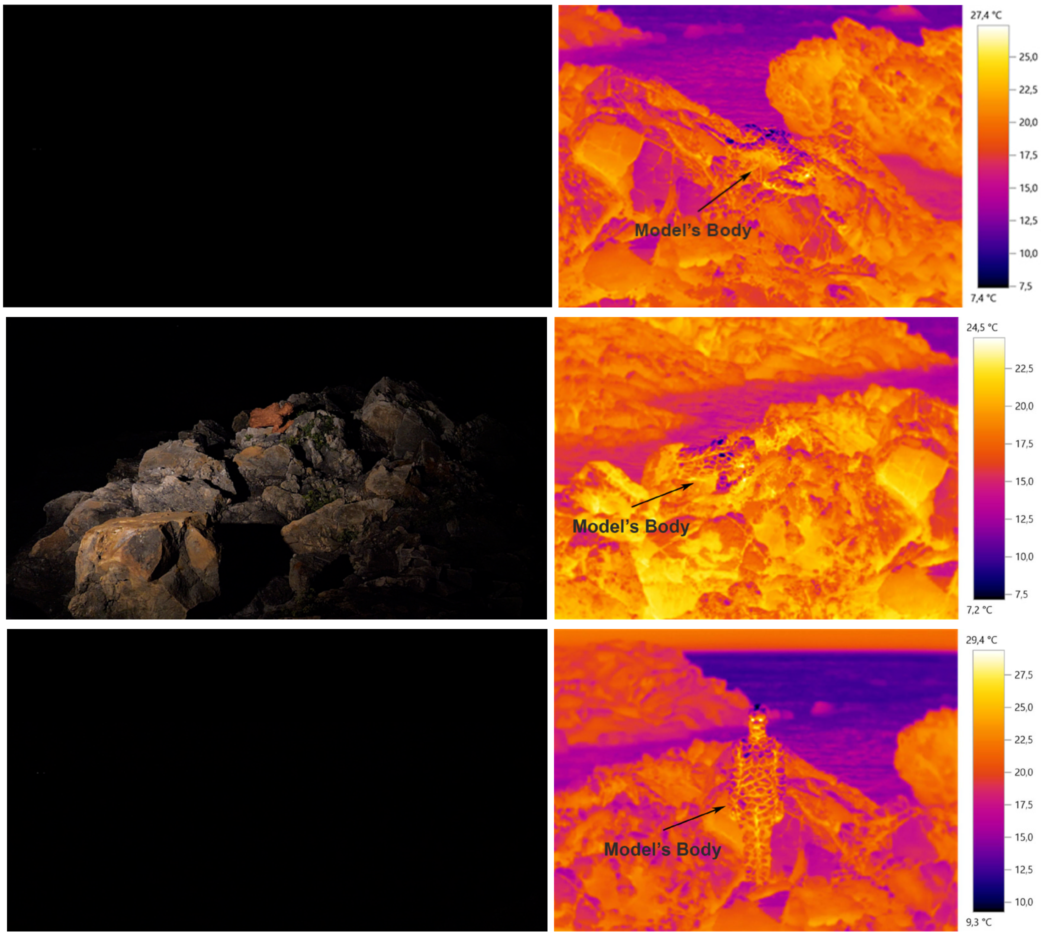
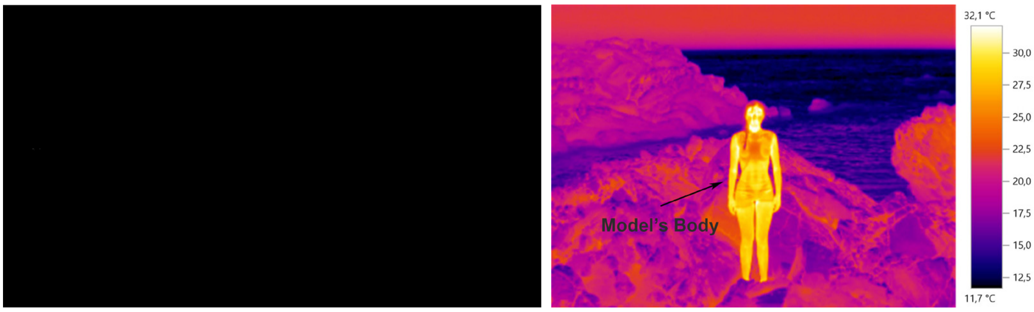


Fig. 3 The conceptualized thermal camouflage outfit for the nocturnal environment.

The results of the thermal tests of the plain thermal camouflage outfit in the diurnal and nocturnal environment are shown in Fig. 4. In these tests, it is possible to observe the absence of thermal camouflage functionality in clothing, as well as the contrast of the model's silhouette in the background, mainly in the nocturnal environment. In addition, it is possible to observe the orange and yellow colour, derived from the textile material used tight to the body (A5^{*4}), with behaviour similar to the skin colour visible in the thermal vision. In both environments, the body movement does not influence the behaviour of the textile material tight to the body. However, it is possible to observe the magenta and dark orange colours in areas with irregularities, resulting from the interaction and/or intervention of the air.

a)



b)

Fig. 4 The conceptualized plain camouflage outfit: a) diurnal environment; b) nocturnal environment.

Furthermore, the constant atmospheric conditions, similar to those previously tested in the laboratory environment, enhance the good results obtained in the diurnal and nocturnal thermal camouflage outfits as well as in the plain camouflage outfit.

Conclusions

The results obtained show that obtaining dark, blue, black and purple colours associated to the reduced emissivity that the materials emit, is not the only approach to achieve thermal camouflage. In addition, a background without variations of textures also does not allow true camouflage in thermal image, and the clothing must be adaptable to different colours in thermal image/vision from the different interactions between the environment, the human body and clothing.

This study shows that there is a possibility to control colours to design clothing, namely the yellow, orange and magenta colours in thermal image (in the "Iron" range), as it was visible in certain positions/perspectives of a dressed human figure, in the outdoor environment (diurnal and nocturnal) through the use of knitted fabric clothing with the application of printing and sewing techniques. Although the movement is driving instability in the behaviour of the clothing's colours, the use of materials with different emissivity and air manipulation techniques can disguise the military's thermal signature.

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