Chapter title: Colour and camouflage: design aspects

Contents

Abstract:

Camouflage has changed over the last decades to become a discipline with a more scientific and analytical foundation. Camouflage, or counter-surveillance, is the art of going (as long as possible) undetected by an observer. Design of a camouflage system needs to consider a number of aspects. The capabilities of the human as an observer (not only on a physiological level, but also on a psychophysical level) need to be considered. Advanced sensors are used to detect a camouflaged object in wavelengths other than the visible; therefore these sensors' properties also play a major role in the design. The environment of operation dictates not only the colours and patterns, but also the fabric type and other properties (e.g. waterproof, flame retardant, insect repellent, etc). Evaluation of camouflage systems can be done using either a probability of detection (POD) method, or a pairwise comparison method (of which the analytical hierarchy process (AHP) was used by the author). It is foreseen that nanotechnology, where coatings and structures are manipulated on a molecular level, will play a major role towards adaptable camouflage systems.

Author details:

Johannes Baumbach

Council for Scientific and Industrial Research (CSIR),

Defence, Peace, Safety and Security (DPSS),

Optronics Sensor Systems (OSS)

PO Box 395

Pretoria

0001

South Africa

e-mail: jbaumbac@csir.co.za

19 Colour and camouflage: design aspects

19.1 Introduction

Camouflage has been practised by nature and humankind for centuries. The purpose of camouflage is to get close to the prey (enemy) in order to overpower it, or to deceive the hunter (enemy) using camouflage and camouflage principles during the fight for survival. Camouflage as a form of art and science has only started making dramatic progress during World War 2. In his book titled "Camouflage", Hartcup (1979) pointed out that artists were the major contributors to the camouflage effort during the 1930's, just because they have the capability to "see" the world through different eyes. Newark e.a. (1996) also made mention of the extensive use of artists in the early years of camouflage development.

Scientists have seen the advantages of applying knowledge from other fields in the camouflage domain. Publications from the medical, human sciences and behaviour, earth sciences, etc. provided valuable information on how "not-to-be-seen". Electronics and computers changed the way detection is done, moving away from the human as the only detector. Camouflage needed to be more effective, and needed inclusion of wavelengths other than that of the visible spectrum. Investments in printing technology and materials science had to keep up with the requirements of the defence industry, making huge progress in manipulating the chemical, reflective and mechanical properties of fabrics. Modern technology enabled mankind to change materials on a nano-level; the physical building-blocks can now even be manipulated on a molecular level. Camouflage technology has become a press of a button, and not a form of art anymore. Humankind's closeness

to nature, and perception of his natural environment, has been lost in this technological rush. Is it maybe not time to get the ART back in camouflage again?

This chapter will start off with camouflage, and how colour and patterns are used for camouflaging. The basic physiology of the human eye is discussed, where-after an overview of sensors and detectors are then presented. Minimising the probability of detection is of utmost importance, therefore the psychophysical aspects of human vision is discussed. Using a systems approach in camouflage is very important, therefore the factors that influences camouflage pattern design is discussed. After the design phase it needs to be printed on fabric, and evaluated. Various printing techniques are discussed, as well as different evaluation methodologies. Finally some thoughts on future tends, where it is foreseen that nanotechnology will play a major role.

19.2 Camouflage: colours and patterns

Camouflage has been used for ages in the animal kingdom, as well as by humankind, to assist with hunting activities, as well as to assist in survival. However, modern camouflage is approached at a much more scientific level; the how, when and where is today much better understood than 50 years ago.
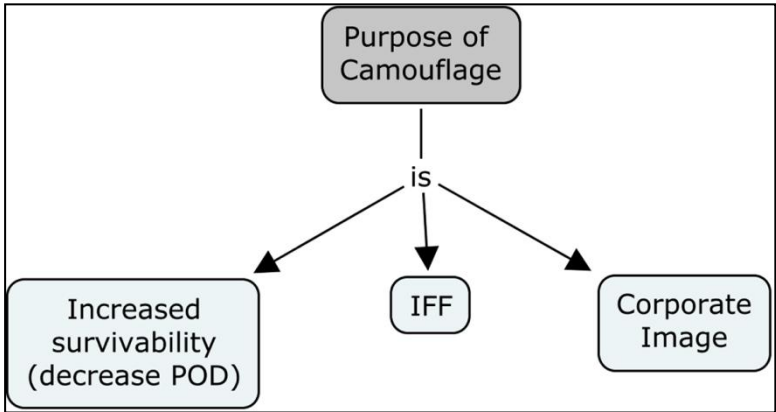

Figure 19.1: Purpose of camouflage

The main purpose of modern camouflage (Figure 19.1) is, through patterns and colours, to:

- Change a target's properties such that it is not recognised as a potential target (i.e. to increase survivability, and decrease probability of detection (POD)).

- Be able to identify a possible target as those of own forces or opposing forces (i.e. Identify Friend or Foe (IFF)).

- Identify a person or piece of equipment as belonging to a specific military force by the corporate image a unique pattern or design exhibits.

One of the most important aspects of camouflage patterns is that the pattern needs to be optimised for the envisaged tactical distance. This was already realised in 1942 during the Second World War by Norman Wilkinson, who held the position of "Inspector of Airfield Camouflage" for the British air force (Hartcup, 1979). He realised that camouflage patterns on aircraft hangers became patches with a homogeneous colour at long distances (due to the spatial resolution of the human eye; as well as backscatter in the atmosphere, which degrades the optical quality of the image), while at closer ranges the patterning becomes obvious and actually accentuates the target.

Two distinct methods for achieving camouflage through the application of colours and patterns on surfaces are:

- Blending. The colours and patterns on the target are such that they blend with the environment. The intensity of the colours does usually not vary significantly in this case. A good example from nature is a lion, which colours blend very well with the grass. A camouflage pattern employing this principle is the British DPM: Desert pattern (DPM: Disruptive Pattern Material).

- Disruption. The aim of disruption is to change the telltale outline or shape of an object, in order to reduce probability of detection. The patterning of the colours is used to draw the observer's attention away from the underlying shape of the object. Disruption is usually achieved using colours with high intensity contrast or colours with large differences in chromaticity. The former Rhodesian camouflage pattern, which has large, contrasting patterns, is an example of a disruptive pattern. Countershading, as observed in the animal kingdom, forms part of disruption. An example is the Impala antelope, found in Southern Africa. This antelope has a very light belly which, together with the shadow from the upper part of the body, disrupts the shape such that it appears to be more flat-surfaced, rather than the natural rounded shape. Shape is one of the primary clues used for distance estimation; hence it will have an advantage over its predators. The same principle is used on aircraft: the underside, which is usually in the shadow, is often painted a lighter colour. This also lowers the contrast with the background, when viewed from below.

19.3   Human perception

We, as humans, live in a colourful world, where the arrangement of colours is forming certain patterns, which forms certain shapes. The combination of these two gives meaning to the perception of our world. Colour is so integral to our existence that we assume it as a given. However, because colour is so "natural" to our existence, we usually miss the complexity of colour perception and colour measurement. One of the most important things to remember is that every person has their own interpretation, perception and meaning to colour. The perception a person has of "green", will differ from every other person, just because they don't have each other's eyes and emotional attachment to that specific "green".

19.3.1 The human eye (physiological)

The information of the outside world (images in this case) enters our bodies via the eye, which is an imaging sensor. The eye has, like all detectors, a few physical attributes, which determines the quality of the image. The cornea is the outer part, mainly responsible for protection (to keep foreign particles out and to prevent ultra-violet radiation reaching the retina), but also responsible, together with the lens, to focus the image on the retina. The retina contains the photoreceptor layer, where photons are absorbed and converted to electrical impulses (analogous to the CCD sensor of a camera system). The iris, like any camera system, controls the amount of light entering the eye.

The rods and cones, which are the eye's photoreceptors, are distributed in various densities throughout the retina. Cones are short and thick, and are highly concentrated in the foveal area (centre part) of the retina. Their density rapidly decreases towards the outer part of the retina (periphery), with a more or less constant distribution through-out the rest of the retina (as shown in Figure 19.2, after Osterberg, 1935). The horisontal axis on the graph is representing the eccentricity of the eye, as shown in the diagram of the eye. The vertical axis in the graph represents the density of receptors (10^3/mm^2). Cones consists of three different photoreceptors, which are sensitive in the red (L-cones), green (M-cones) and blue (S-cones) regions of the visible spectrum, thus enabling humans to have colour vision. These are used during the day (photopic vision), when illumination levels are high.
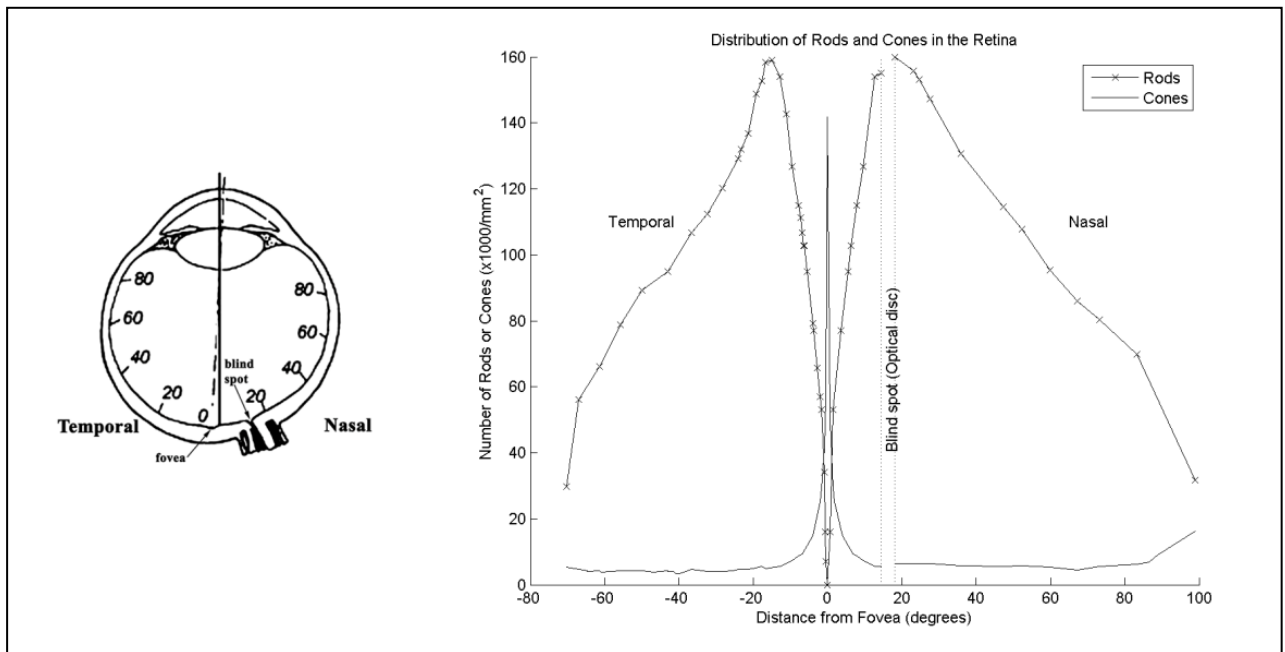
Figure 19.2: Distribution of rods and cones in the human retina (after Osterberg (1935))

Rods are long and thin, and are more concentrated towards the periphery of the retina. As seen in Figure 19.2, the maximum density is at 25° eccentricity, whereafter it decreases towards the outer edges of the retina. Rods only have one type of photopigment and can therefore only detect differences in luminance (i.e. these "see" only in monochrome). During night-time, when illumination is low and the iris wide open, the rods are used for vision (called scotopic vision). Peripheral vision in a dark environment is much better than foveal vision due to the low distribution-density of rods in the centre part of the human eye. However, rods are about two-and-a-half times more sensitive than cones (Figure 19.3, after data published by Wyszechy and Stiles, 1982, p256). They do not contribute to photopic vision, because of "over-exposure" when illumination is high (a process called bleaching).
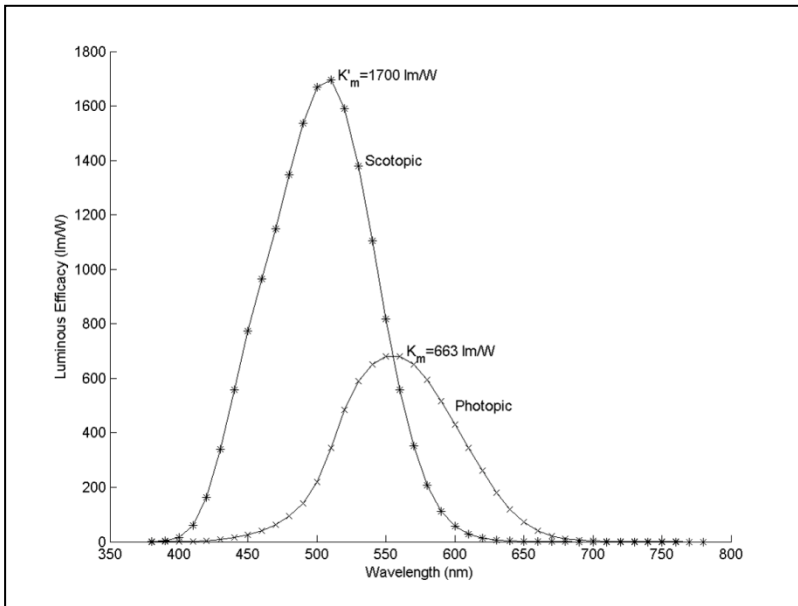
Figure 19.3: Scotopic and photopic curves for spectral luminous efficacy (after data published in Wyszechy and Stiles, 1982, p256)

Due to the variable nature of rod and cone distribution (Figure 19.2), it can be concluded that the foveal part of vision is in high-resolution colour, while the peripheral has very low colour resolution and -perception (Graham, 1966). This also depends on the intensity of the source, but for general daylight viewing this holds true.

Resolution is defined in terms of the angle per line pair (or cycle).One line pair is indicated on the high-contrast bar target shown in Figure 19.4. Data for the resolution of the human eye differ from reference to reference; but the consensus value for good lighting conditions seems to be 0.5 minute of arc per line pair (Burle Industries, 1974; Graham, 1966).
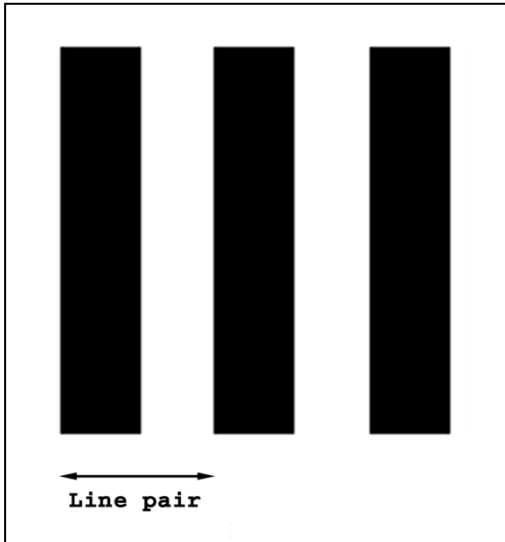
Figure 19.4: Resolution target, with one line pair indicated

19.4   Imaging

19.4.1 Detection

Detection, in this context, refers to the entire observation part (detection, recognition, identification and classification) of the reconnaissance process. Detection immediately implies that some kind of sensor is observing a scene. Sensors (or detectors) could be broadly grouped as human senses, optical sensors, electro-optical sensors and a group labelled "other" (Figure 19.5). We shall focus on optical sensors, while the fourth group of sensors, labelled "other", will not be discussed here. All of these sensors provide information to the human's senses, in order to enhance the human's situational awareness.
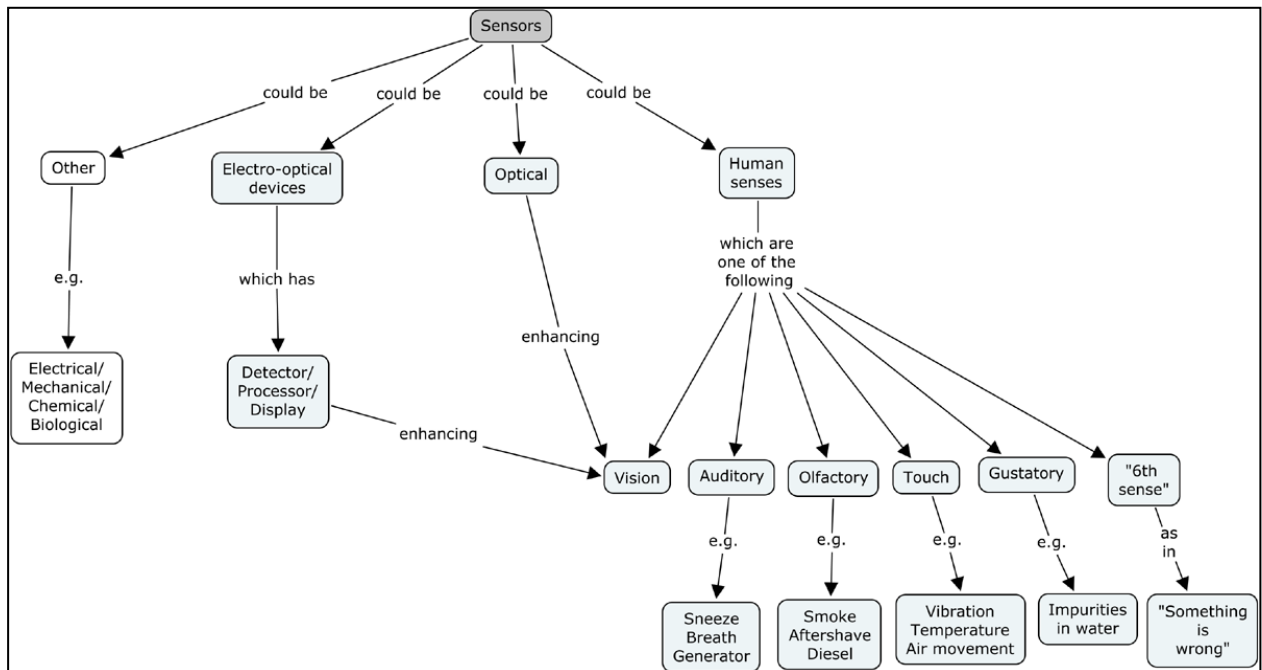
Figure 19.5: Different sensors, as well as the human senses

19.4.2 Imaging devices

In general, the visible spectrum comes to mind, where a human is observing his environment either with the naked eye, or via optical- and electro-optical aids like binoculars, night vision goggles (NVG) or forward looking infrared (FLIR) cameras. These systems capture the electromagnetic radiation of a scene (in abovementioned cases the visible, near infrared and the thermal infrared parts of the spectrum) and either enhance the image or convert the radiation into a format for human observation.

Electro-optical devices usually form part of an observation platform. Examples are long-range observation systems (consisting of cameras in any of the visible, near infrared (NIR) and thermal wavelengths as well as processors and a display) and radars. The past twenty years are known for the dramatic increase in computational power as well as a huge reduction in the physical size of computing systems. These advances had a huge impact in the versatility and capability of imaging systems. Real-time image enhancement, automatic target tracking and fusion of images from

different camera systems have become an increasingly easy and popular image processing technique.

In the vast majority of cases a human is part of the total surveillance system. The human analyses and interprets the information provided by the imaging system, which results in a particular action to be taken.

19.4.3 Human visual system as an imaging device

Due to the emphasis placed on imagers and image analysis (which relates to human vision), the other five sensory inputs are sometimes greatly ignored, even though they could provide a wealth of information on the battlefield. These five are also shown in Figure 19.5. The first is the auditory sense (hearing). A metallic sound in the bush or the absence of the croaking of frogs in a swamp may indicate imminent danger. The second sense is olfactory (smell). The smell of cigarettes, which could travel very far in the field, could provide information on human activity. The third sensory input is touch. Low-frequency vibrations, which travel very far, could be felt when touching the walls of a building. Some sources define temperature (or rather temperature differences) as a separate sense, but for our purposes this is grouped under touch. Just by the temperature of rocks it is possible to determine if a fireplace was used recently. The fourth sensory input is gustatory (taste). Although not as highly developed as eyesight, some persons might be able to detect a difference in the taste of water, after contamination with soap. The last sense, namely a person's "sixth sense", is more difficult to define. This is the subconscious "feeling" that says: "something is wrong". All six abovementioned senses work together, and the combination of all of these need to be addressed to apply successful camouflage. However, eyesight is in most cases the final sensor used to determine (usually identify) the threat level.

19.4.4 Vision and colour

The human visual system is, due to its physical and physiological properties (as mentioned earlier), most of the times superior to visual-spectrum camera systems. The human eye is very sensitive to colour differences, especially when these colours are observed in a controlled environment (typically a lighting cabinet with a neutral, homogeneous colour). The smallest colour differences the human eye can see depend very much on the colour itself. Colour differences can be defined in terms of hue, chromaticness (or chromaticity) and lightness.

A person's hue discrimination (yellow, red, blue and green are different hues of colour) can be determined by the Farnsworth-Munsell 100 Hue Test. Graham et.al. (1966) published data on various studies to determine the hue discrimination of the human eye. Although some discrepancies exist, the general trend is that the human eye is most insensitive to hue differences in the blue and red region of the spectrum.

Colour differences could also be defined in terms of chromaticness. Chromaticness is a property of a specific hue, e.g. pastel green, pale green, midgreen and pure green. The human eye is most insensitive to chromatic differences in the green region of the spectrum. This is best illustrated by the MacAdam ellipses, as defined in the CIE 1931 chromaticity diagram (Graham et.al. (1966)).

The third property of colour is lightness. The lightness specifies how light (or dark) a specific colour is, e.g. light green or dark green. The human eye is most sensitive in the discrimination between light colours (the Farnsworth-Munsell 100 Hue Test consists of pastel colours).

A general guideline is that the eye is able to resolve colours separated by one CIELAB-difference unit (i.e. dE = 1). A wealth of information is available on the CIELAB colour space, a few

references are given under "Further Reading": CIELAB colour space. However, when colours are observed in relation with others, or put in a certain context, your eyes can really play tricks on you!

19.4.5   Psychophysics of human vision

Purveslab at the Center for Cognitive Neuroscience, Duke University, has published numerous papers on the psychophysical visual effects people experience. One of the most striking examples of how the eye perceives colour in context is described by Lotto and Purves (2000). The discs, described in this paper, are similar to the two cubes with coloured squares (similar to a Rubik's cube) shown on the laboratory's website (Purveslab, 2011). The two cubes look similar, but one is shown in a blue environment, while the other one is shown in a yellow environment. The darkest squares of the cube in the yellow environment are blue. Yellow is the second-lightest colour of the cube in the blue environment. But, when abovementioned blue and yellow squares are isolated from their respective environments (taken out of context), all of them have the same colour! The reason for this is called colour contrast. Although the spectral returns from the said squares are the same, the perception is that they exist in environments with different illumination, and therefore they elicit different colour stimuli in the brain. Camouflage patterns, with colours having this kind of behavior, are effective in a wide range of environments.

Humans base their sensory inputs (vision in this case) on their experience of the physical environment. Without even thinking we assume nature has a light source providing illumination from above (sun), therefore shadows are supposed to fall on the ground. With that comes the assumption that curved surfaces in nature will have a lighter side on top (illuminated by the sun) and a darker side on the bottom (everything in the shadow, example of the Impala earlier in the text). The shadow is connected to the object (object standing on the ground) most of the times. Also, if a few clues are given (a number of similar objects), we immediately assume that all objects

with the same geometry will have the same properties. Purves has combined all of these real-life experiences with the Cornsweet effect (Purves e.a. (1999) in order to illustrate how humans perceive their environment; images can be found on Purveslab (2011)).

Various psychophysical aspects of human vision, applied in the context of camouflage patterns, are described by Baumbach (2008), Troscianko et.al. (2008), Friškovec and Gabrijelčič (2010). These include perception of colour, contrast, lightness, shape, texture and depth. The Gestalt principles, as formulated by the German psychologist Max Wertheimer, is considered to be a very simplistic method to describe the psychophysics of vision, however, it describes the basic concepts very well, and which have a direct relation to camouflage principles (these concepts are shown in Figure 19.6):

- Proximity: elements near each other appear to be grouped together.

- Similarity: elements that look similar appear to be grouped together.

- Continuity: smooth, straight or curved lines appear to belong together. Intuitively a person will select A-B and C-D; A-C and B-D are very improbable selections.

- Closure: figures are completed, even with some information missing. The two triangles in the figure are clearly recognisable.

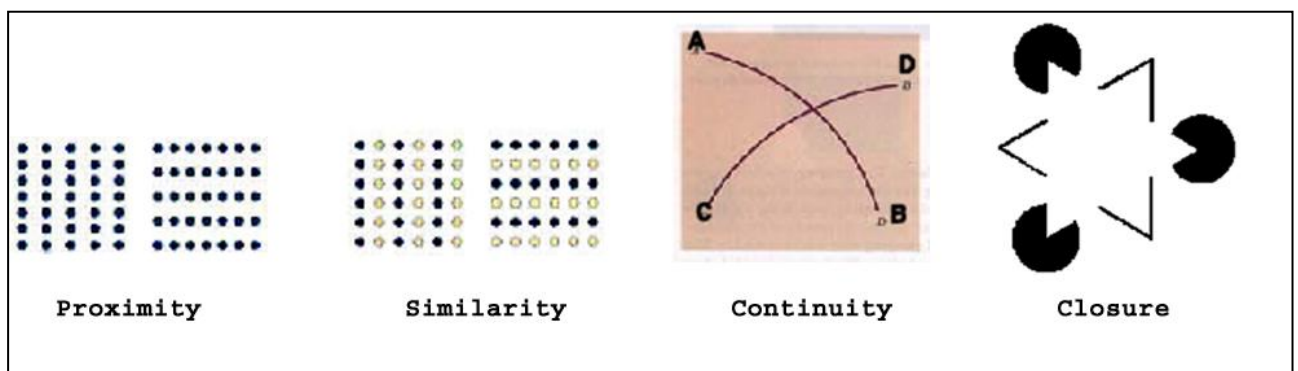- Common fate: elements moving in the same direction appear to belong together.

Figure 19.6: Illustration of proximity, similarity, continuity and closure

19.4.6 Colour deficiency and camouflage detection

A significant number of humans have some kind of colour deficiency (Graham (1966)), and it affects more men than women. Colour deficiencies occur when a person cannot distinguish between different hues, due to defects with some photoreceptors. Studies including different nations on different continents indicated a similar trend for all Caucasians: about 8% of males and 0.4% of females are affected with a colour deficiency. African, Indian and Asian people have a lower frequency of colour deficiency (Graham et.al. (1966), Howard Hughes Medical Institute (2008), Verhulst and Maes (1998), Al-Aqtum and Al-Qawasmeh (2001)). The most common deficiencies are in the red and green, called protanopia and deuteranopia. The blue colour deficiency is called tritanopia, but this is a very rare condition.

People with a colour deficiency (especially protanopes and deuteranopes) are believed to have an advantage in terms of camouflage detection. This has been studied by Saito e.a. (2006) and Morgan e.a. (1992), and it was confirmed that colour deficient people have increased capability in recognising colour-camouflaged shapes (not that colour-true persons can't see the shapes, they only take longer to recognise them).

19.4.7 Multi- and hyperspectral imagery

Conventional digital imagery consists of three channels, namely a red (R), green (G) and blue (B) channel. Various attempts to characterise scenes spectrally (or at least retrieve the colorimetric (colour) values), using the RGB values, were attempted with varying success (Hong, Luo and Rhodes (xx); Solli e.a. (2005); Bajcsy and Kooper (2005)). However, RGB values achieve a good perceptive image on computer displays, notably in the gaming industry and simulation environment. A reference standard with known properties is usually inserted in the scene, and final adjustments to the image, depending on the environment's illumination and the type of display, can be made in order to accurately render the image.

Hyperspectral imagery, on the other hand, implies that every pixel in the image has a full spectral signature associated with it. By convention, "hyperspectral" means more than 100 spectral bands (per pixel, in this case). This is particularly useful for physics-based applications (typically modelling and simulation) as well as environmental monitoring, where the full spectral behaviour of a scene is important for image analyses. Hyperspectral sensors are usually used in the airborne role; their size, weight and line-scan method of operation is very cumbersome if deployed as ground-based sensors. In the airborne role these images are used, for example, to identify pollutants in a river's catchment area. These are done by looking for a specific "signature" reflectance at a specific wavelength.

Unlike normal CCD cameras used in surveillance applications, ground-based hyperspectral imagers have limited resolution due to the enormous amounts of data that are collected during measurement. Field or laboratory systems have a typical spatial resolution of 256 x 256 pixels, although they can go up to 1600 x 840 pixels (see references under "Further reading": Hyperspectral cameras). In the ground-based role hyperspectral sensors, when calibrated, are capable of providing useful colour data about objects and even whole scenes. However, because of the multi-orientation of objects in a scene, the user needs to understand how energy/light is reflected from surfaces (as described by the Bi-directional Reflectance Distribution Function (BRDF)), and the possible limitations the BRDF poses in accurately predicting the colour of a specific surface.

19.5   Measurement

19.5.1 Measuring colour on samples

Radiometers and photometers provide a scientific method to measure colour. By measuring a calibrated spectral reflectance from a surface one has full flexibility in terms of which colour space,

standard observer and standard illuminant the data needs to be presented in (as defined by the CIE, see Further reading). Spectroradiometers are usually used during outdoor measurements, where any sample's reflection is measured in the environment of occurrence, with natural illumination. This is the easiest method to measure nature's colours, because it is sometimes impractical to collect samples to measure in the laboratory. The following guidelines were found to provide the most useful data during field measurements:

- Measure with the sun at the back. This will minimise the probability of specular reflections (mirror-like reflections), which could affect the measurement significantly.

- Measure an area as homogeneous as possible. Shadow effects, curvatures and texture effects could significantly alter the measurement.

- Make several measurements in the same area, this will ensure statistically significant data.

- Measurements are usually the most accurate between 10:00 and 14:00, during which time the sun's radiation is passing through the thinnest atmospheric layer. Atmospheric influences due to dust and aerosols are minimised during this period. Also, due to the high illuminance of the sun the integration time of the detector is minimised, resulting in low signal-to-noise ratios.

- Measure over a distance which is as short as possible. Atmospheric backscatter (inter-reflections due to the molecules in the atmosphere) and scintillation (small-scale fluctuations in air density, usually caused by temperature differences close to the ground) could change the data considerably.

- Try to avoid windy conditions. Standards used for referencing could soil easily, dust could damage the equipment and the target area is constantly moving.

- Use appropriate reference standards. Measurements on glossy samples should be calibrated with a glossy standard, and vice versa for matt samples.

- Keep your reference standard as clean as possible, and limit exposure to the sun (i.e. protect from ultra-violet (UV) and thermal radiation). This will ensure a longer lifetime for the standard. Check your standard every time before going to the field (make a reference measurement, and compare with previous reference measurements made). Calibrate all equipment and standards to (at least) national reference standards, to ensure repetitive and accurate measurements.

Using a spectrophotometer to measure colour of natural objects (e.g. vegetation, soil) could be very cumbersome, because the samples need to be harvested and handled correctly before transportation to the instrument. Live specimens quickly begin to change, and without appropriate preservation and handling, would yield inaccurate results (Foley e.a. (2006), Richardson and Berlyn (2002)).

19.5.2 Perceived and measured colour

The colour of a sample changes depending on the surface properties of the sample, the orientation with respect to the viewer and the position of the light source. The illumination of the light source is reflected from the surface, and scattered in all directions. The scattering effect is defined by the Bi-directional Reflection Distribution Function (BRDF). The perceived colour might look very different from the measured colour, which is due to the position and orientation of the light source, the observer and the sample, together with inter-reflections from other surfaces in the environment. The perceived colour and the measured colour need to be recorded simultaneously to achieve accurate and repeatable results. The perceived colour is determined by comparing the colour of a sample with that of a standard sample (e.g. a sample from a colour index).

19.6   Camouflage design considerations

19.6.1 Systems approach

Like any product or project, a systems approach is of utmost importance when a new camouflage pattern is developed. It is important to produce a proper requirement analysis, where the user is involved in providing information regarding the doctrine, tactics and operational scenarios; mostly from a strategic level, but equally important on a tactical level.

As an example consider the development of a camouflage pattern for a uniform. A thorough analysis needs to be done and a number of strategic decisions need to be taken before a decision is made on a specific camouflage pattern. The first decision is a critical step, but the reasons are sometimes not so obvious: "Does the defence force really need a (new) camouflage pattern?" Why does the current pattern need to change? If the change is motivated due to the current pattern been ineffective (scientific proof needs to be obtained) and a current (or future) threat has been identified, it is sensible to start a design-change process. The second decision is: "Do we have the necessary resources to make a change?" Coupled to this must be the realisation that the necessary skills-base needs to reside in a suitable research and development organisation as well as the monetary support to achieve the necessary development needs to be available. This step will cover the necessary development: research, design, test and evaluation. The pattern could then either be a bought-in item, or a research contract, or internally developed. The competing designs must be evaluated according to an approved evaluation process. After this lengthy (and rather expensive) process, as sensible decision to either approve or reject the design needs to be made.

After approval of the design it needs to be implemented. Procurement of fabric (production) needs to take place. An industry, capable of supporting the manufacture of the uniforms, is also very important. Dyes with special properties are used during the printing process, and industry needs to

be able to produce prints with the specified properties, to the required standards. Logistical supply of the quantities and sizes issued to the warehouses/stores need to be considered as well.

19.6.2   Main factors influencing a camouflage design

Several factors drive the decision for a certain camouflage design. These are shown in Figure 19.7. The dimensions of the equipment determine the design: large vehicles usually have large patterns, smaller items like uniforms have small patterns. The design is tightly coupled with the doctrine. Vehicles operating from under camouflage nets do not necessarily need to have a camouflage pattern. If the engagement is at long distances, the pattern will be larger, if it is at very short distances, the pattern will show more detail. The envisaged threat or observer and his equipment, together with the environment, play a major role. If the envisaged threat has access to advanced technology (e.g. night vision goggles, thermal detectors), characteristics other than just visible camouflage needs to be considered. The pattern would need to satisfy the requirement of low detectability with the human eye as well as with any of these sensors. The probable engagement environment also needs to be considered: woodland areas will have greener patterns, desert areas will have browner and lighter patterns.
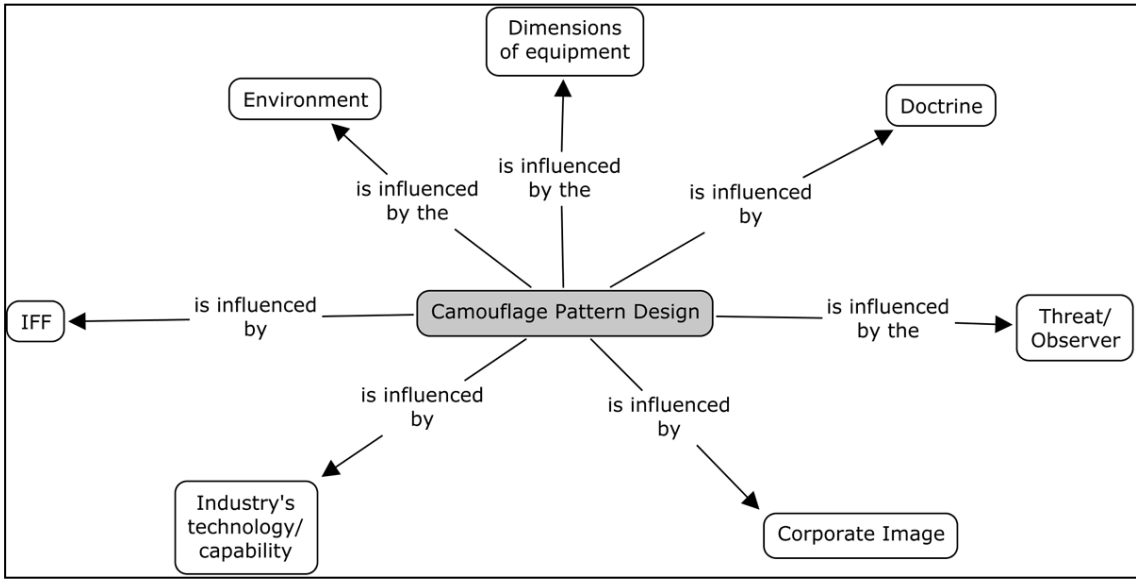
Figure 19.7: Factors influencing camouflage pattern design

Secondary considerations (though just as important) are that the new pattern needs to portray a unified corporate (and professional) image of the organisation. The pattern needs to be unique and recognisable (although not less effective in the operational role) to also satisfy a requirement of IFF. The last consideration is that the industry (either local or international) needs to have the capability of reproducing the pattern. It is possible to design a pattern so complex that it cannot be manufactured in a high-volume production facility.

19.7   Producing samples for evaluation

It is not always possible to produce the pattern on the exact fabric that will be used on the final product. However, it is much easier to evaluate the pattern and colours if it is printed on the final fabric, from which garments (e.g. camouflage jackets) are made. Different methods for producing samples for evaluation can be used, each with its advantages and disadvantages. These methods are discussed in the next few paragraphs.

19.7.1   Dye-sublimation heat transfer printing

The first possible method to print patterns on fabric is through a process called dye-sublimation heat transfer printing. This printing method uses special inks in an inkjet printer to print the design onto sublimation paper (very similar to newspaper). The paper is then placed on the fabric, and through heat and pressure applied to it the design is transferred to the fabric. This process is extensively used in the advertising business to print banners, flags and ties. Polyester fabric is used almost exclusively, because polyester is a very common, synthetic fibre; the dyes can be captured in the fibre structure when applying heat (in the region of 180 ^{o}C), thereby increasing its colourfastness and wash-ability. Polyester usually has a glossy appearance, which is a disadvantage. Also, with so

many different steps (design – print – sublimation transfer) and variables (humidity, temperature, pressure, time) in the process it becomes very difficult to control the colours of the final camouflage design.

19.7.2   Fabrics inkjet printer

Certain inks can be printed directly on fabrics. A wide range of fabric printers is covered by the FLAAR reports (http://www.wide-format-printers.org). Printable fabrics including polyester, cotton, poly-cotton, lycra, nylon, etc. The design is printed directly onto the fabric, and heat is applied to fix the inks to the fibres.

This printing method is a very good alternative to produce designs for evaluation on the correct fabric. Small-scale print-runs could be done very easily and with relatively low cost. Complex designs are also not a problem, because the design is directly transferred from the electronic source onto the fabric.

One of the possible problems that might arise is that the printer does not have a calibration profile for a specific fabric (e.g. a 60/40 poly-cotton mix). Quite an extensive process then needs to be followed to produce such a calibration profile. A second possible stumbling block is that the inks do not have the required gamut range in order to produce a specific colour in the design. This might be especially true for dark colours. Once the gamut-limit of the inks is reached the only other alternative is to use the traditional screen-print process.

19.7.3   Screen-printing process

The screen-print process is the traditional, high-volume process to print designs on fabrics. The two different types are flatbed- or roller screens. The principle for both is the same: the design is

engraved on a set of screens, one screen per colour. The maximum number of colours is usually around 6, but through novel processes like blending and fading it is possible to achieve more perceptible colours. The capital layout of the screens make it expensive to print small amounts of fabric, but once production runs is required it is a very cost-effective method. The dye-stuff used to print each specific colour is a pre-mix of different base-colours. It usually takes a few iterations to achieve the correct colour on the fabric. Over and above the blend of pigments, it also contains special binders, ultra-violet (UV) stabilisers or even fire retardants. Once the design is printed on the fabric, the fabric goes through a high-temperature process to fix the dyes to the fibres.

19.8   Evaluation techniques

Once the camouflage design is finalised and printed onto fabric, either a part of a uniform (like a jacket) or a full uniform is made to evaluate in the laboratory as well as the field. Field evaluations are of interest here, of which two basic types are commonly used: Probability of Detection (POD) and pairwise comparison. These techniques are described below.

19.8.1 Probability of detection

The evaluation technique most extensively used for camouflage evaluation is the POD method. McManamey (20xx) describes three variations of POD (McManamey calls it the Classic Detection Assessment (CDA)). During a POD evaluation a number of observers (one at a time) are looking at a number of targets (not simultaneously), at different distances. While the observer is moving alongside a pre-determined track, the distances at which he sees the target is noted (see also Anitole et.al. (1988)). The second variation of this technique is to have the observer stationary in one location, with the target moving closer. The third variation is to photograph the target at different distances; the photographs are then showed to observers on a screen (see also Natick (2009)). By using statistical methods the probability of detection is determined. The North Atlantic Treaty

Organisation (NATO) has published an extensive guideline on using this technique for camouflage evaluation (NATO, 2006). The results from such an evaluation are typically expressed in graphical form: distance from target on the x-axis, and the probability of detection on the y-axis (Figure 19.8, data only for illustrative purposes).
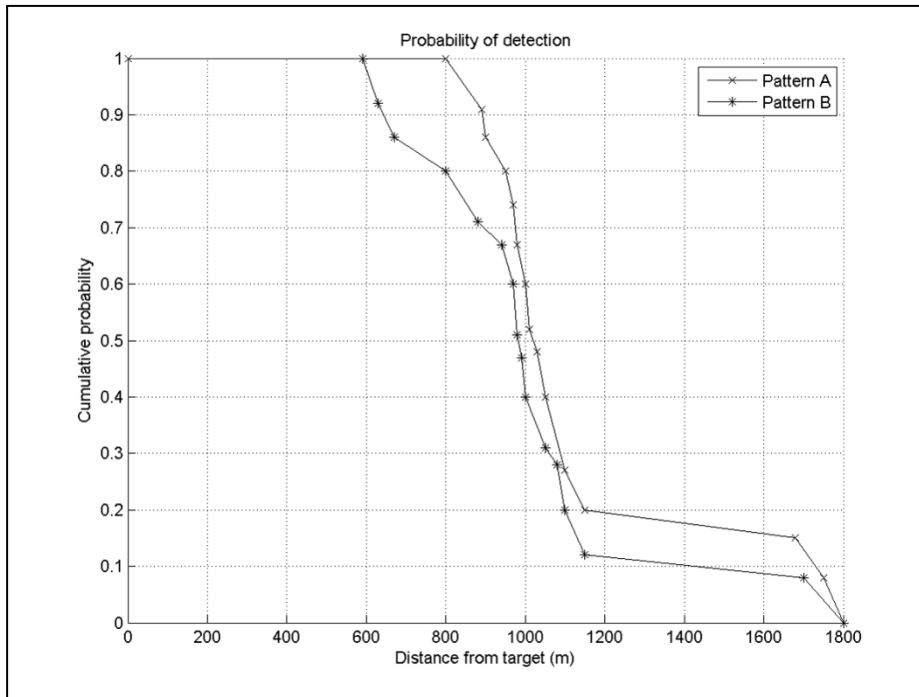

Figure 19.8: Probability of detection (POD), data only for illustrative purposes

19.8.2   Pairwise comparison methods

The first pairwise comparison method used for camouflage evaluation is the Law of Comparative Judgment (LCJ). LCJ is a psychophysical tool for performance evaluation, developed by Thurstone and described by Torgerson (1958). It is a forced-choice pairwise comparison method, where in this case different patterns are evaluated two-at-a-time by a panel of observers, and through a statistical method the different patterns are ranked in terms of perceptible effectiveness. McManamey (1999) describes in detail how the method is used. In another publication he compares the POD techniques

mentioned above with the LCJ (McManamey (20xx)). He found good correlation between the methods. The use of LCJ for camouflage evaluation is also described by Baumbach (2008).

Hepfinger (2010) describes a pairwise comparison method (in a simulation environment), where the perceptible effectiveness is rated in terms of the number of times it is selected by the observers. Although this method would indicate the most effective pattern, it does not have a metric on HOW MUCH better one design is in comparison with another one.

The second forced-choice pairwise comparison method is the Analytical Hierarchy Process (AHP). During a LCJ evaluation the observers only need to state which pattern they perceive as the best, while with AHP they also need to state by HOW MUCH the one design is better than the other. Baumbach has found the AHP to be a more meaningful method to evaluate camouflage patterns (Baumbach, 2008; Baumbach, 2010). The first reason for it being a more effective method is that the result for AHP is expressed on a scale from 0 to 100. The result for LCJ is expressed as values on an open-ended scale, which makes comparison between different test setups very difficult. The second reason is that the AHP allows the user to calculate a consistency ratio, and any inconsistent data could be filtered out before including it for further analyses. A graph showing comparative results for an AHP as well as an LCJ evaluation (four different patterns) is shown in Figure 19.9. Note how close the LCJ ranking for Pattern2, Pattern3 and Pattern4 is (right-hand scale). With an AHP analyses of the data a clear separation of the preferences are observed, while the rank of these three patterns change as well.
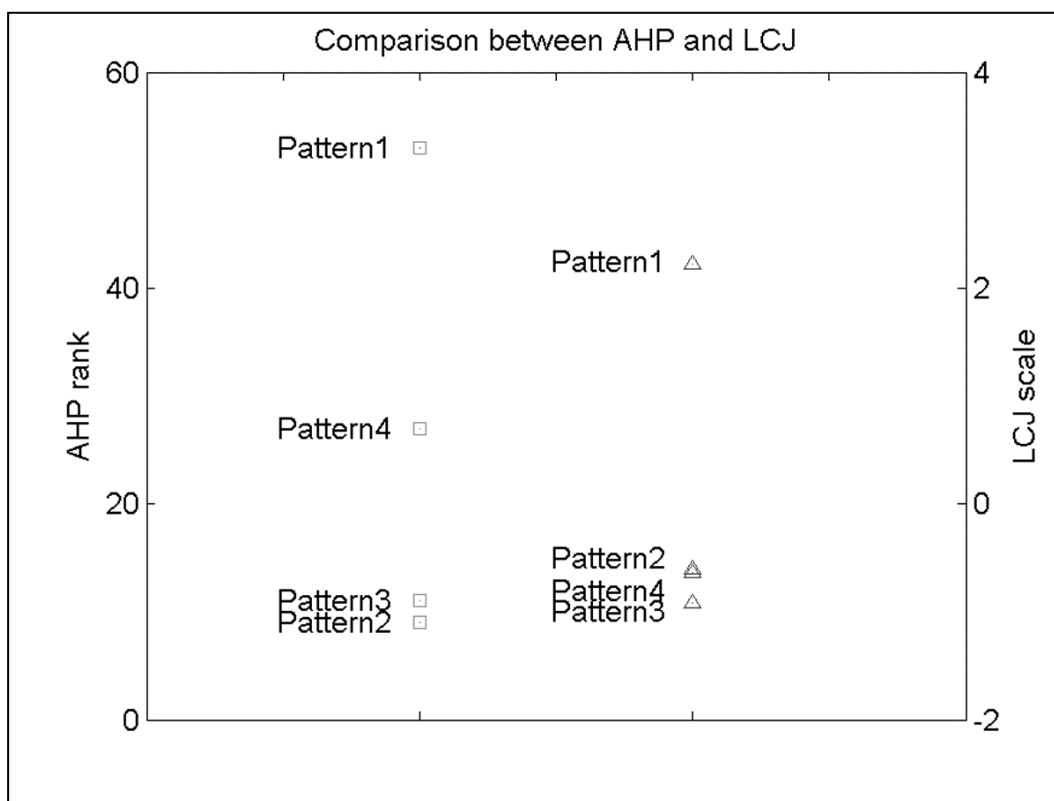
Figure 19.9: Results for an AHP and LCJ evaluation for four different camouflage patterns.

The advantage of using the psychophysical methods LCJ and AHP is that a large number of observers are not a pre-requisite for accurate and statistically significant results, as is the case with a POD evaluation. It is also possible to perform a relative quick evaluation in order to determine the effectiveness of certain designs. The overall effectiveness of a design, however, cannot completely be determined by AHP and LCJ, and can only be fully described by a POD evaluation.

19.9   Future trends

It is foreseen that nanotechnology will play a major role in future development of camouflage systems. Modern technology gives scientists and engineers the capability to modify the properties of substrates and surfaces on molecular level, thereby having the advantage to exploit (and control) certain characteristics of materials and surfaces. Once the capability to do this on a large scale is established, the technologies mentioned below will start to make inroads in modern camouflage.

19.9.1   Camouflage applications

Camouflage, at its best, will always be a compromise between conflicting factors. It is impossible (at this stage) with one system to provide the same level of protection for all seasons, all terrains, all illumination conditions, all weather conditions, etc. Therefore, optimisation of the client's requirements in terms of the stated performance, as well as the available skills and know-how in the industry is essential. The face of war has changed dramatically over the past few decades. Today's war is a faceless one; a good example is that the majority (70% to be exact) of Australian soldier casualties in Afghanistan is the result of improvised explosive devices (IED's) (Brig W Budd, Australian Defence Force, Keynote Address Land Warfare Conference 2010, Brisbane). The majority of conflict situations for developed countries have a large stand-off distance, precision-guided missiles to eliminate targets, remote piloted aircraft to do surveillance. Advanced technology like thermal imagers or night-vision goggles (NVG's) have made it possible to operate at night, when no visible camouflage is required. In many ways the traditional soldier has become a diplomat and negotiator, a keeper of peace. In these situations he (or she) needs to be visible and free-moving.

The ultimate wish for any soldier is that his system must provide camouflage on demand, in any of the wavelengths, against any background (and then change the pattern according to the background as he is moving). A whole section in Wilusz (2008) is dedicated to the chromic properties of dyes, where the colour could be changed on demand. The electrochromic and thermochromic properties will be briefly discussed here.

Significant research effort is put into textiles with electrochromic (colour-change through electric stimulation) properties. Wheaton, e.a. (2010) demonstrated the concept of using an electrochromic process to change the colour panels. The panels were a plastic/textile hybrid, and the colour change

was from yellow to green. From the photos it is evident that specular reflections are still a problem. Invernale, e.a. (2010) investigated the change in colour gamut in terms of the base-colour of the fabric. Usually the base-colour is white, research for colour changes in fabrics with a coloured base shows promise. A few links to electrochromic research is given in the section Further reading: Electro-chromic.

Thermochromic pigments can change colour depending on the temperature. Heated panels, similar to those described by Wheaton (2010), could be used to initiate a colour change. In a camouflage situation this could be used to change the camouflage colours and/or patterns. It could however disclose the camouflage position when observed with a thermal sensor. Thermochromic pigments have become stable enough to be used in the commercial and consumer market, see Further reading: Thermochromic.

"Wearable displays" are also proposed as an alternative for active camouflage (cloaking). A valuable asset will have a display towards the observer's side, while a camera will capture the scenery behind the asset. The display will then duplicate the scenery towards the observer, thereby masking the asset with the environment. Since it is an active method, luminance levels of daylight need to be achieved, together with matching in any of the other wavelengths (NIR, thermal). In 2007 Defence Research and Development Canada (DRDC) published a report on active camouflage systems for the infantry (McKee K W, Tack D W (2007)). The conclusion was that serious technological hurdles needed to be solved before any practical systems could be fielded. An example of a system for the commercial market can be found at PCWorld (2011).

Duke University (DukeToday (2006), Duke Pratt Scholl of Engineering (2011)) announced the development of materials with special properties, called meta-materials. These materials are able to

"bend" electromagnetic energy around objects in such a manner that the object would appear as not to be there. These materials are only manufactured in highly experimental, small scale set-ups. The properties of these materials are only possible due to the advances in nanotechnology (as mentioned earlier).

19.9.2 Non-camouflage applications

The modern soldier is also very technology orientated (and very dependent on it). Communication (radios, cellphones), navigation (global positioning systems (GPS), computers) and observation (cameras, NVG's and thermal imagers) are used extensively, but these need batteries to operate. Solar cells make it possible to recharge batteries, but the power demand still exceeds the supply. Solar panels used to be glass- and silicon based, but these started to make way for flexible solar cells, which could be rolled and transported easily. New developments in the chemical field will make it possible to coat fabric with organic pigments, effectively changing the soldier's garments and load-carrying equipment into a battery-charging device (Shtein (2008)). During 2009 the University of Glasgow was involved in research regarding wearable solar cells for soldiers (University of Glasgow (2009)). The aim is to reduce the load of soldiers through reducing the number of batteries and intelligent charging of batteries. More information on the consumer-side of this technology can be found under Further reading: Wearable solar cells.

19.10   A final word

On a tactical level, the art of camouflage is not in what a soldier wear, but rather on how well he blends with the environment, using what the environment has to offer. Camouflage is mostly a matter of common sense (after Sir Thomas Merton, 1941 (Hartcup G (1979)), and a LOT of it. Today camouflage is still very much a passive method used as a force multiplier. Camouflage,

concealment and deception go hand in hand, and together with doctrine, discipline and dedicated training a mission can be successfully completed.

19.11   Further reading

19.11.1 CIELAB colour space

The CIE (International Commission on Illumination) is an international body which coordinate the worldwide cooperation and exchange of information on matters relating to illumination, colour, vision, image technology. It is recognised as an international standardisation body, and has defined and standardised several colour spaces. For more information on the CIE and the CIELAB colour space (an internet search on the term "CIELAB" will produce thousands of additional links):

http://www.cie.co.at/ [Accessed July 2011]

ISO 11664-4:2008(E), *CIE Colorimetry — Part 4: 1976 L*a*b* Colour Space*, CIE, Vienna

19.11.2 Electrochromic

The links below provide very interesting reading on electrochromic research and technology [all sites accessed July 2011].

http://www.docstoc.com/docs/77588701/Electrochromic-devices--From-windows-to-fabric

http://www.mrs.org/s11-abstract-h/

http://www.annualreviews.org/doi/pdf/10.1146/annurev-matsci-062910-100344

http://www.talk2myshirt.com/blog/archives/49

http://www.docstoc.com/docs/77588701/Electrochromic-devices--From-windows-to-fabric

http://getfuturistic.wordpress.com/2010/05/08/clothing-designs-from-the-future/

http://www.printedelectronicsworld.com/articles/advanced-electrochromic-displays-find-markets-00000149.asp

http://ynvisible.com/?q=technology

19.11.3 Hyperspectral cameras

Some examples of the latest portable hyperspectral cameras can be found at the following websites

[All sites accessed June 2011]:

http://www.specim.fi/products/spetral-imaging-products/spectral-cameras.html

http://www.neo.no/products/hyperspectral.html

http://www.hyspex.no/products/hyspex/allspecs.php

http://www.techexpo.com/WWW/opto-knowledge/lctf-cam.html

http://www.surfaceoptics.net/products.php?id=2

19.11.4 Thermochromic

Commercial and consumer applications of thermochromic materials [all sites accessed July 2011].

http://www.geeky-gadgets.com/thermochromic-urinal-makes-peeing-fun01-05-2011/

http://www.mindsetsonline.co.uk/images/SMARTCOLO.PDF

http://www.colorchange.com.tw/english/index.php/thermochromic-material.html

http://www.qcrsolutions.com/Site/Thermochromic_Pigments,_Inks,_and_Plastics_%7C_QCR_Solutions_Corp.html

http://www.chromazone.co.uk/?gclid=CLaRxOOs76kCFWcJtAodkjzPmw

http://www.tut.fi/units/ms/teva/projects/intelligenttextiles/chromic.htm

19.11.5 Wearable solar cells

Some product incorporating wearable solar cells are listed below [all sites accessed July 2011].

http://www.physorg.com/news2394.html

http://www.envirogadget.com/tag/wearable-solar-panels/

http://www.talk2myshirt.com/blog/archives/456

http://www.presseagentur.com/interactivewear/detail.php?pr_id=1391&lang=en

http://www.plusplasticelectronics.com/energy/wearable-solar-cell-to-aid-uk-soldiers-27331.aspx

http://www.psfk.com/2009/09/wearable-solar-panel-vest-for-outdoor-workers.html

19.12   References

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[last accessed June 2011].

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