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Camouflage assessment: Machine and human

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ABSTRACT

A vision model is designed using low-level vision principles so that it can perform as a human observer model for camouflage assessment. In a camouflaged-object assessment task, using military patterns in an outdoor environment, human performance at detection and recognition is compared with the human observer model. This involved field data acquisition and subsequent image calibration, a human experiment, and the design of the vision model. Human and machine performance, at recognition and detection, of military patterns in two environments was found to correlate highly. Our model offers an inexpensive, automated, and objective method for the assessment of camouflage where it is impractical, or too expensive, to use human observers to evaluate the conspicuity of a large number of candidate patterns. Furthermore, the method should generalize to the assessment of visual conspicuity in non-military contexts.

1. Introduction

Military personnel and equipment need protection from detection during conflict. Camouflage is the primary method to achieve this, frequently through coloured textures that match the background and/or disrupt the object's outline [1–3]. Assessment of effectiveness can be carried out in a number of ways. The most intuitive method is to use human participants as observers. Such an apparently straightforward procedure, however, is not only limited by uncontrollable conditions, such as the weather: it is also impractical given the large variety of objects/patterns that one might want to evaluate and the range of environments one might want them to be assessed in. Field trials are also expensive and, in some circumstances, may not even be possible. They also do not lend themselves to precise isolation of exactly what leads to the failure of camouflage, something that a paired comparison of otherwise identical target-present and target-absent scenes would allow. Photo-simulation attempts to overcome weather constraints and problems with inaccessible environment-types by using photographic or synthetic imagery. Recent advances in synthetic rendering are impressive; however, current methods are still computationally expensive and the images are unrealistic at small spatial scales due to the current limitations of simulating realistic ray scattering. Furthermore, human experiments are necessarily subjective and do not readily allow evaluation of camouflage against autonomous systems perhaps operating using different spectral bandwidths than the human vision. A computational approach is therefore helpful in overcoming the limitations of assessing camouflage when using human observers. Such a computational model should be ideally designed, in the first instance, in accordance with the human visual system, since it will be performing the task of a human observer and, if it is to replace subjective assessment, needs to be compared with human performance. More generally, however, such a system could be adapted to have a different 'front end' (e.g. infra-red sensor, hyperspectral sensor). Therefore it is surprising that a biologically motivated design for the assessment of camouflage has not been implemented.

This omission means that the confidence and extendibility of current models and metricsare low, fallingshort in their ability to cope with high dynamic range (i.e. natural) [4–6], semi-automatic labelling or tracking of the target [7], non-probabilistic and non-scalable distancemetrics to highdimensional data or multiple observations given many images [8–10]. Human behavioural data need to be recorded to assess the coherence between human and

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model observers. This requires tasking human and model observers with the same experiment, based on a stimulus set from the real world: outdoor environments and militarily relevant objects.

2. Method

An experiment was devised so that human participants and a model observer could both be tasked with it, allowing for direct comparison. This method section is broken down into the three components that comprise this study: (i) images of objects placed in real world scenes were photographed and calibrated; (ii) a human experiment, using a protocol from psychophysics, recorded unbiased performance for recognition and detection of these objects; and (iii) the design of the visual observer model, and modelling the discrimination task.

2.1. Stimuli

Targets were photographed in two outdoor environments in the UK: Leigh Woods National Nature Reserve in North Somerset (2°38.6′ W, 51°27.8′ N), which is mixed deciduous woodland, and Woodbury Common in Devon (3°22′ W, 50°40′ N), a heathland used for Royal Marine training. A replica military PASGT helmet (Personnel Armor System for Ground Troops, the US Army's combat helmet until the mid-2000′s) was the chosen object used in the experiment and visibility was manipulated by changes in helmet covers varying in both colour and textural appearance (Fig. 1). The camouflage patterns worn by the helmet were United Nations Peacekeeper Blue (UN PKB), Olive Drab, Multi-Terrain Pattern (MTP, as used by the British Army since 2012), Disruptive Material Pattern (DPM, the dominant British Army pattern prior to the adoption of MTP), US Marine Pattern (MarPat) and, for the Woodbury Common experiment, Flecktarn (as used by the Bundeswehr, the German Army). These patterns were chosen not for the purpose of evaluation per se, but to reflect a range of styles (e.g. unpatterned Olive Drab, DPM as a subjective human design, MTP and MarPat based on spatio-chromatic analysis of natural scenes, but MarPat being 'digital' or pixellated), with UN PKB as a high visibility control.

For the computational approach to be useful, the spectrum of visibility across the patterns should be highly correlated in the model and human observers. Scene locations were selected on a meandering transect through the habitats, at 20 m intervals and alternating left and right. If the predetermined side was inaccessible or inappropriate due to occlusions then the opposite side of the transect path was used, and if neither side was accessible the interval was ignored and the next location in the transect was used. At each location the object was placed in a 3×3 grid resulting in nine images. The distance of each row of the grid was 3.5, 5 and 7.5 m. The scene was also divided into 3 arcs: left, middle and right. The combination of distance and left-right positioning mean that, in the subsequent tests on humans, the location of the target within the scene was unpredictable. This resulted in nine images of each helmet per location for analysis, plus a scene including a Gretag-Macbeth Color Checker chart (X-Rite Inc., Grand Rapids, Michigan, USA) for calibration. The orientation of the helmet in each photograph was set an angle drawn randomly from the uniform distribution {0, 45, 90, 135, 180, 225, 270, 315°}. For efficiency of implementation, the list of random angles was generated before going into the field. Each scene was also photographed without a helmet present. Photographs were taken using a Nikon D80 digital SLR (Nikon Ltd., Tokyo, Japan) with focal length 35 mm, exposure 1/30 and F-Number 16.
An example of these images can be found in Figs. 2 and 3, using two different helmets. RAW images (Nikon NEF format) were captured and these were subsequently converted to uncompressed 8-bit TIFF and calibrated. Images were calibrated by recording luminance and chromatic spectral values of the Gretag-Macbeth colour chart in the field using a Konica Minolta Chroma Meter CS – 100A colour and luminance meter (Konika, Tokyo, Japan). This process was repeated three times to average over the natural variation in lighting from moment to moment. The spectral values were transformed to the CIE sRGB colour space after first converting them to the CIE XYZ colour space. The process was then repeated in the lab from a projected image from the projector. A cubic polynomial approximated the relationship between the two sets of RGB measurements. Images were then calibrated using the coefficients of the polynomial for each RGB channel. Not only does this procedure avoid having a colour chart in every single image, but also it calibrates the entire pipeline in a single step: calibrating the camera, projector and images individually could result in over-fitting or multiplicative errors.

2.2. Human experiment

2.2.1. Participants and materials

A human experiment using 22 participants for the Leigh Woods dataset and another 20 participants for the Woodbury Common dataset was conducted. Each of the two experiments had an equal proportion of each gender. Images were projected onto a 190×107 cm screen (Euroscreen, Halmstad, Sweden) from

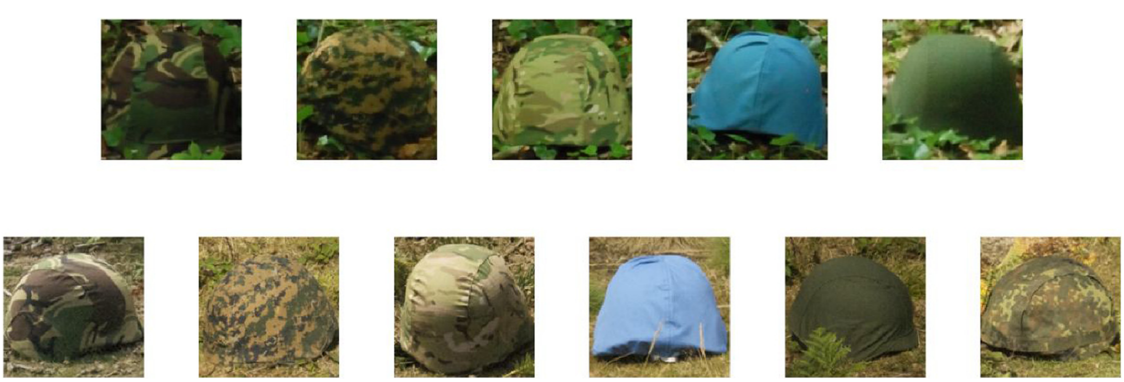

Fig. 1. Example cropped helmet images from real world scenes.
An example of each camouflaged helmet cropped for recognition purposes. From left to right the patterns that the helmet wears are DPM, MarPat, MTP, UN PKB, Olive drab and Flecktarn. The top row are the helmets from Leigh Woods and the bottom row are helmets from Woodbury Common. Flecktarn was only used in Woodbury Common.