Active Multispectral Camouflage Panels

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Not being seen 'in the field' or in other words, a combat situation, can provide a critical advantage towards survivability and protecting military assets. Current camouflage technologies and approaches are fixed and unchangeable post-manufacture, and even when designed for terrain-specific environments, remain limited in their desired effect. We have developed active, multispectral camouflage panels based on conducting polymers that provide for visual and Near Infrared (NIR) reflectivity to adapt (in real-time) to the ever-changing natural environment. This will furnish the material basis that is fundamental to an automatically adapting, bespoke camouflage solution for protecting military vehicles and assets.

Keywords—camouflage, active camouflage, multispectral, concealment

I. Introduction

Military camouflage has been the subject of continuous improvement and research for over 100 years - ever since the realisation that, supplying troops and equipment with colours matching the ambient environment could lead to improved protection and survivability. To this day, visual camouflage remains to be an important 'first line of defence' since the human observer is still central to surveillance, detecting potential threats. Though many more sophisticated sensing technologies exist, arguably, if you are not 'seen' and not expected, then these detection methods are less likely to be brought to bear. This however, might change in the future. In the context of the "industry 4.0" revolution, where repeatable, labour intensive tasks in manufacturing are now done by cyber-physical machine systems, it is not unreasonable to expect that the future theatre of conflict will also see a lot more automation in certain areas. One example could be surveillance and detection – it is a labour intensive repetitive task that one day might be outsourced to machines, with sensitive, multispectral detectors, more powerful optics, and processing algorithms that could far outperform a human observer. Another aspect of this industrial revolution is the greater accessibility of technological advances. With complex surveillance and processing technology becoming cheaper and widely available, the technological advantage enjoyed by advanced militaries may disappear. To this end, protective measures must keep up with advances in covert surveillance and detection.

Despite improvements to camouflage design patterns, the main drawback to existing techniques is that once fabricated, the patterns and colours are set and unchangeable. The 'Multicam' camouflage system is designed to provide concealment in a wider range of environments, though they are not as effective if used outside of the one environment they are matched for. By contrast, what we propose is an active multispectral camouflage system, designed to sample spectral signatures of ambient environments and then display an optimally background-matched pattern to a 'camouflage array' of cells affixed on a military platform. Herein we present the latest stage of the development of the hardware component - the camouflage panels.

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II. Catch me if you can

There are several aspects to consider when designing an effective camouflage strategy. Firstly, there is the survivability onion model [1] which defines 'layers of protection' in the field from 'not being there' (added more recently) to 'not being seen' to 'not being targeted', etc. Secondly, there are Johnson's criteria [2] often used in the design of sensor systems to assess performance. These criteria define four steps in image analysis: detection, orientation, then recognition and identification. Some camouflage systems (eg. SAAB's Barracuda) rely on this mechanism, disturbing the shape of the protected object so that even if it is detected, it can't be easily recognised or identified. Finally, there is a mnemonic doctrine routinely conveyed to army cadets: the 'S' elements of camouflage [3] that provides rationale for the how and why objects are seen. It can be found in several variants and generally calls for consideration of shade (colour), shine, shape, shadow, spacing, silhouette, sound, speed (movement) and surrounding. It can be used in many ways: in the design of optimal camouflage and concealment, and for teaching search and detection strategies. One example is detection and recognition of divers in sonar signatures which amplifies the diver's silhouette to stand out when analysing shadows on a sonar reflective background [4].

III. Colour changing materials

There are a range of colour changing materials that have found use in commercial products such as ophthalmic lenses, toys (hypercolour), thermometers, and many others [5]. These materials can be classified into two major groups – as active or passive materials depending on how the change of the colour is activated. The passive colour change materials, such as photochromic [6] or thermochromic [5] materials react to the changes in environmental parameters, such as ultraviolet (UV) radiation level and temperature, respectively, while active materials, can be switched on and off on demand. One group of active materials is electrochromics [7]. They can be found in a form of a thin film or a suspension, and they range from inorganic materials (eg. tungsten oxides or vanadium oxides) to organic materials such as viologens or conducting polymers.

Some of the electrochromic materials (inorganic and viologen based) have already been commercialised and can be found in high-end automotive dimming interior rear view mirrors (Gentex corporation [8]) or in the Boeing 787 Dreamliner windows [7]. However, they are limited in their switching speed and high power consumption, where to reach full contrast it takes approximately 60 seconds, and the electric potential must be applied and held to maintain the colour state. Also, viologen based electrochromics are limited to the colour tones of blue and grey.

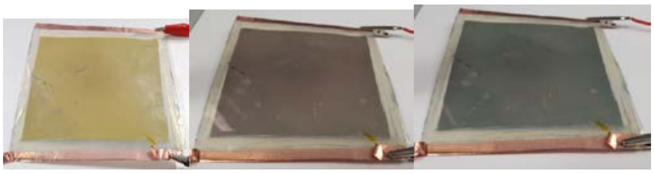

Fig 1. Polypyrrole based active camouflage device in three distinct colour switching states

Another group of electrochromic materials are conducting polymers [9]. These materials present several promising properties. They require low voltage to switch, offer colour memory effect (they retain their switched colour without a continuously applied voltage) and they have switching speeds in the range of seconds. Several chemistries of conducting polymers have been developed and they range from polyanilines, polythiophenes, polypyrroles and several other derivatives. These materials can produce a wide range of colour tones we find closely suited to those used for military concealment.

IV. Active Camouflage Design

Our work has centred on the development of electrochromic camouflage panels that actively change. We have developed and refined fabrication methods for synthesis of the conducting polymers, deposition of the electrodes and assembly of the device. Currently the technology is at TRL 4 and in the next stages an image analysis and control unit will be added to create a complete camouflage system, and the colour range will be tuned to matched specific applications.

These panels can be made with rigid, or flexible materials, allowing for application on a variety of defence asset platforms, resources and equipment. The panels are based on conducting polymers with a ‘sandwich’ structure, where the active material – a conducting polymer is deposited onto a transparent substrate coated with an transparent electrode materials. Two such panels are assembled facing each other with an electrolyte filling space between them. The colour change is the result of an electrochemical reaction that occurs when the low electric potential (in the range of 1.5 V, as shown in Fig. 2) is applied to the electrode. This drives the ions from the electrolyte and oxidises/reduces the polymer. The conducting polymers, similar to doped semiconductors, for different oxidation states present different light absorption properties due to changes in the bandgap structure. This is observed as a change of colour in the visible range.

V. Multispectral Solution

One interesting feature in the spectral response of conducting polymers, is that the electrochromic effect for these materials often extends to the near infrared range (NIR) and beyond.

A typical UV-visible-NIR spectrum of a conductive polymer contains 3 distinct absorption regions [10]. The absorption peak at 300 – 500 nm is related to the absorbed light trigging electron transition across the energy gap. This peak is most pronounced for conducting polymers in the reduced state, since then they behave more like semiconductors. conducting polymers in their oxidised state present additional energy levels related to polaron and bi-polaron states (which are the charge carriers responsible for polymers being conductive).

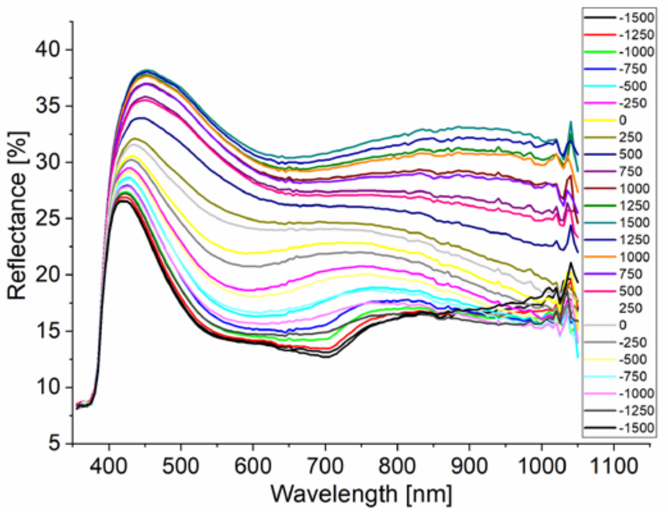

Fig. 2. UV-visible-NIR spectra of PEDOT based active camouflage device, showing 20% contrast in NIR range used for Night Vision Devices, the legend on the right side presents voltage applied to the device (in mV) resulting with respective spectral response.

The presence of these levels allows for additional electron transitions, and shows as a much less pronounced, wide peak at approximately 600 nm, related to polaron, and a wide band with the onset at 800 nm and extending into to approx. 2500 nm (see Fig 2 and 3), related to bi-polaron transition. The exact location of these peaks depends mainly on the chemistry of the polymers, and can be further affected by types of dopants and electrolytes used in the system.

In practical applications, the presence of the wide absorption band in the NIR and short-wave infrared (SWIR) that can be ‘switched’ on or off makes the materials attractive for a multispectral camouflage device. The tests performed on several conducting polymers showed the reflectance changing at more than 20% in the range of approx. 15 – 35% at wavelengths between 800 nm and 1000 nm (Fig. 2) and between 1400 nm to 2000 nm (1.4 – 2 μm) (see Fig. 3). Moreover, the reflectance of the electrochromic device can be set at intermediate levels, by applying different electric potentials to the device (see Fig 2). This will allow for fine tuning the reflectance and colour of the device to provide better match to the surrounding.

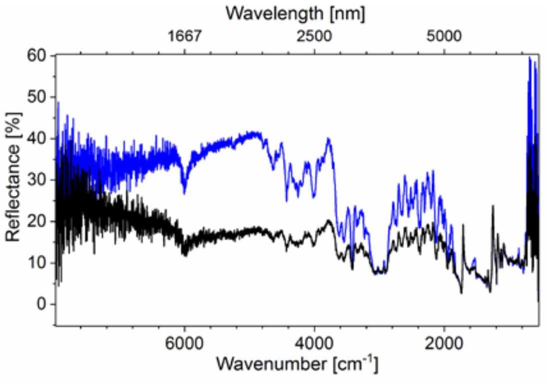

Fig. 3. FTIR reflectance spectra of PEDOT based active camouflage device, showing reflectance against wavelength on the top axis and wavenumber on the bottom axis

The majority of natural surfaces – such as grasses, soil and trees present NIR reflectivity of 10 – 60% [11]. This compares well with the NIR reflectance of the camouflage devices (10-40%), making them potentially viable for NIR camouflage, though further tests need to be performed.

VI. Prototypes

A range of prototype panels of electrochromic materials developed from conducting polymers as described in the preceding sections were fabricated and tested for colour, durability and flexibility. Devices made on flexible substrates were additionally subjected to bend test where they were switched while bent around tubes of various diameters.

The outline of the Bushmaster PMV was used to demonstrate how these electrochromic panels could be incorporated into a camouflage system including a disruptive pattern overlayed onto the panels (see Fig. 4.) to add shade and spacing to the camouflage. This prototype demonstrated the ability to change the camouflage colour when moving between forest and arid environments. The other materials we regularly fabricate allow for a change of colour between yellow-brown and grey (see Fig. 1.), blue to yellow, and brown-red. New materials and new colour effects are currently being explored to broaden colour response. In the future the complete camouflage solution can be made by added patterning and using the panels as a 'dot matrix display' to project the image of the surrounding.

Fig. 4. The outline of the Bushmaster PMV with active camouflage panels and shade rendering mask, in two colour states.

VII. Alternative Application of the Technology

Since the electrochromic devices demonstrated here can be assembled in either reflective configuration (as in the active camouflage) or transmissive configurations, it opens the possibility for a new range of applications in optical devices. This demonstrates technology convergence of the proposed camouflage device solution with a problem in optical displays relevant to defence applications.

Fig. 5. The early prototype of AR headset contrast control device (photographed through Epson BT-200 AR glasses), demonstrating improvement of the augmented image contrast (a flower) in the outdoor application

One example is for contrast control in Augmented Reality (AR) Head Mounted Display headsets and Heads Up Display platforms, that find rising interest from ADF and US military. These are systems that display a live view of the real world with elements 'augmented' by computer-generated perceptual information. These can be overlaid images, as for the flower in Fig. 5, or overlaid text such as warnings or interpretive information. The opportunity for applications in these display technologies is that the contrast of assisted and/or augmented digital images is highly dependent on variable ambient lighting conditions, where the displays are used. Existing products lack variable contrast control when needed, for example, outdoors.

Equally, units with dimmed visors are too dark for indoor use. Our proposed solution (Fig. 5.) allows for dynamic dimming of ambient light sources (with switching speeds of less than 1 s) to improve contrast and quality of digital images, without the need for excessively increasing the brightness by the visual projection system. Moreover, the fabrication methods we use (unlike traditional conducting polymer deposition methods) allow for fabrication of optical grade materials. Such devices may lend themselves to be useful to applications where variable light conditions impair the use of augmented/assisted display technologies, which might include asset management, training, and critical mission displays (eg. for First Responders (Police, Ambulance and Fire services) and military Special Forces).

CONCLUSIONS

A prototype concept of a new generation of multispectral, active camouflage panels has been presented. These devices offer enhanced protection and concealment by changing the colour of the active material. Separately, the technology can be applied in alternative fields, with one already validated example, being that of active, variable contrast control for AR smartglasses and display systems.

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