Perception Enhancement through Additional Illumination

Jiuai Sun, Melvyn Smith, Abdul Farooq, and Lyndon Smith

***Abstract*—This paper presents a new strategy to counter camouflage by capturing (one more) additional images of same scene. The strategy is based on a technique we call 'two-light photometric stereo', which can remove disruptive reflectance from luminance images to generate synthetically shaded images related only to surface shape information. It becomes easier to perceive concealed information from virtually shaded images free from the effects of a confusing reflectance texture. Various rendered images, corresponding to different synthetic illumination configurations are generated to offer an improved visualization, countering the effects of camouflage. Experiments results are presented using scenes possessing different conventionally 'difficult' back and foreground camouflage. The results verify that the proposed low-cost and robust technique may be used for perception research, security and military applications. Future work will extend the method to more challenging objects in outdoor environments.**

***Index Terms*—Photometric stereo, camouflage, reflectance image, light source, rendered image.**

I. Introduction

Optical deception is a main form of camouflage that provides a method of concealment, by obscuring the signature of an object, allowing otherwise visible objects, for example personnel or military objects, to become indiscernible from the surrounding environment [1], [2]. Evolutionary competition has led to natural organisms with concealing colorations and even the ability to vary reflectance characteristics such that light is absorbed selectively giving an appearance characterized by reflected light, blended with the surroundings. In modern military situations, the deployment of clothing with disruptive coloured patterns and the use of painted organic designs on vehicles, ships, aircraft and buildings, have become essential to ensure potential targets blend-in with their environment.

Contrary to modern camouflage techniques, which have become very well understood and well developed, little research has been undertaken on counter camouflage techniques aimed at breaking down visual concealment, even though there are obvious implications and significant potential benefits for military applications. Infrared multispectral or hyper-spectral sensing methods have been tried. These assume the existence of a distinguishable difference in the spectral characteristic between the target and background [3]. However, frequent false alarms may occur due to the spectral variation of the background. Extra information is needed to improve the performance of spectral based techniques before they can be reliably deployed in reality [4].

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Jiuai Sun is with Machine Version Laboratory, University of the West of England, UK (e-mail: Jiuai2.sun@uwe.ac.uk).

As opposed to making use of expensive sensing elements and/or making assumptions regarding any spectra differences between background and targets, other work has employed conventional imaging to detect targets by using image enhancement techniques. Tankus et cl. developed a convexity-based camouflage breaking technique from Thayer's principle of counter-shading [5]. Bhajantri et cl. employed co-occurrence matrix based texture features to detect defective regions (where the obscured target is thought of as a camouflage 'defect') by a cluster analysis method [6]. By detecting the data difference of successive frames, Huang et cl. enhanced those pixels with high probability of spatial and intensity density [7]. The above image enhancement methods attempt to reveal interesting targets based on using luminance images only, which is similar to most image processing or computer vision research where the luminance images are input as the information source. When the scene being observed is not complex, i.e. the variations in reflectance are small and sparse, and the shape of the target(s) of interest is smooth across the whole area, the luminance image can be approximated by a shaded image with uniform reflectance. So the shape of the target(s) can be inferred from the gradient or other operators performed on the luminance image(s). However it will be very difficult to deduce the scene through only a single luminance image when the target is deliberately obscured with some disruptive textured patterns or structures, as for example in the case of the natural or artificial camouflage techniques mentioned above.

To improve the capability of counter camouflage techniques, we desire to first remove the confusing reflectance used to conceal hidden objects. In this paper a novel two light source photometric stereo method, which needs only one image more than tradition image based counter camouflage strategies, is proposed. By taking advantage of this single additional image, scene reflectance can be effectively removed from the luminance image, dramatically improving the perceived visibility of concealed objects.

II. Method

A. Image Formation

The perceived luminance of Lambertian surfaces is a combination of external and internal factors. Extrinsic factors may include external illumination conditions and imaging sensor performance, which can be modelled or simplified through a prior knowledge concerning physical properties, e.g. relating to manufacture/construction of the imaging and illumination system, or by testing/calibration. Another group of factors known as intrinsic factors include reflectance features and the 3D shape of the object(s) in the imaged scene. These factors concern the physical properties of the object and mainly determine the appearance of an object [8], [9].

The image intensity at each pixel is combined by a reflectance image and a shading image [10]. The shading image is the product of the incident light and the shape of the object. So a simplified equation of image formation can be written as:

$$\mathrm{I}(m,n) = r(m,n)\vec{l}(m,n)^T\vec{N}(m,n) \tag{1}$$

where I and r are the intensity and reflectance of the pixel (m,n) , $\vec{l}:(l^x,l^y,l^z)$ and $\vec{N}:(N^x,N^y,N^z)$ are two unit column vectors representing the incidence direction and the surface normal, superscript T represents the transpose of a vector.

In cases where the scene is simple and involves no camouflaged, the reflectance image r may be approximated by a constant map. Here the luminance image perceived by a sensor, or the human eye, can be approximated by the shaded image from which the shape of an object is easily recoverable using a 'shape from shading' method [11]. On the other hand, when the reflectance is not simple and cannot be approximated by a constant map, there are few systems able to decompose the shading image from one luminance image without additional information or assumptions being provided.

B. Two-light Photometric Stereo for Counter Camouflage

The photometric stereo technique has proved to be an effective solution for the recovery of surface shape, even when there are variable textures presenting on the imaged surface(s). As known from equation (1), the technique involves at least three luminance images acquired under different illumination conditions taken from the same view point to recover both reflectance and surface shape. However these minimum three light sources required sometimes limit the application of the technique. Considering the main task of any counter camouflage application is only to get rid of, but not recover the reflectance disruption from the background, a novel strategy employing only two lights has been developed for this purpose.

Fig. 1. shows two lights located on either side of a camera where their incident directions are represented as $\vec{l_1}:(l_1^x,0,l_1^z)$ and $\vec{l_2}:(l_2^x,0,l_2^z)$ respectively. Both light sources are in the XOZ plane of the optical coordinate system.

So we can obtain two equations from the two light sources according to (1):

$$I_1 = r(l_1^x N_x + l_1^z N_z) \tag{2}$$

$$I_2 = r(l_2^x N_x + l_2^z N_z) \tag{3}$$

Dividing (3) by (2), the reflectance effects can be cancelled out. In addition, the gradient in the *x* direction can be obtained as:

$$\mathrm{G_x} = N_x/N_z = (I_2 l_1^z - I_1 l_2^z)/(I_1 l_2^x - I_2 l_1^x) \tag{4}$$

According to a phenomenological model of a surface which reflects an equal amount of light in all directions [12], the rendered shaded images can be represented by:

$$S(m,n) = r\left(l^x G_x + l^y G_y + l^z\right) \tag{5}$$

If a virtual light condition is set to the case: $\vec{l_i}:(l_i^x,0,l_i^z)$ and uniform reflectance is represented by a constant value of *C*, the shaded images can be modeled as:

$$S_i(m,n) = C(l_i^x G_x + l_i^z) \tag{6}$$

Therefore luminance images are able to be produced even with an absence of gradient information in another direction. From the experimental results we will show that the rendered images obtained in this way are remarkably convincing. The two lights can be located on either side of a camera so that the reflectance effects can be cancelled out effectively by dividing two images. In addition, a virtual light condition is able to set for producing various shaded images to make the visualization flexible.

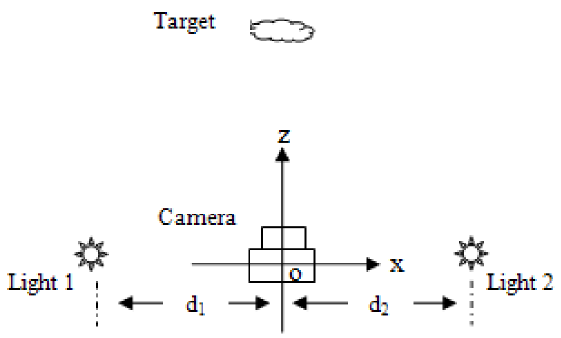


Fig. 1. Illumination geometry of two-light photometric stereo

C. Robustness Analysis

In order to understand the proposed technique and be in a position to make a working practical system, the uncertainty of the two-light photometric stereo method is investigated analytically. As the sensor used to capture all images is the same, the type and amount of noise in the two acquired images should be similar, i.e. they can be approximated by a distribution of mean zero and of the same variance, i.e. 〖 $\Delta I_1 = \Delta I_1 = \sigma^2$. From equation (4), the uncertainty of the system is represented by that of the recovered gradient, i.e.

$$\Delta\mathrm{G_x} = |(l_1^x l_2^z - l_2^x l_1^z)(I_1+I_2)/(I_1 l_2^x - I_2 l_1^x)|\sigma^2 \tag{7}$$

From the expression in (7), it can be generally summarized that the two lights should not be located very close to each other. Otherwise the similarity of the two images will become small, which may make the denominator smaller and so the system unstable. For the convenience of analysis, we will simply examine the following two special cases: firstly with lights distributed symmetrically about the optical axis and secondly with one light co-located with the camera optical axis.

1) Two lights distributed symmetrically along the x axis of the system, i.e. $l_1^x = -l_2^x = l^x$ and $l_1^z = l_2^z = l^z$, so

$$\Delta\mathrm{G_x} = |2l^z/l^x(I_1+I_2)|\sigma^2 \tag{8}$$

Thus, the uncertainty of the system will be determined by the ratio of $|l^z/l^x|$ and the sum of the image intensities (I_1+I_2).

2) One light has same direction as that of viewer, i.e. $l_1^x = 0$ and l_$l_1^z = 1$, so

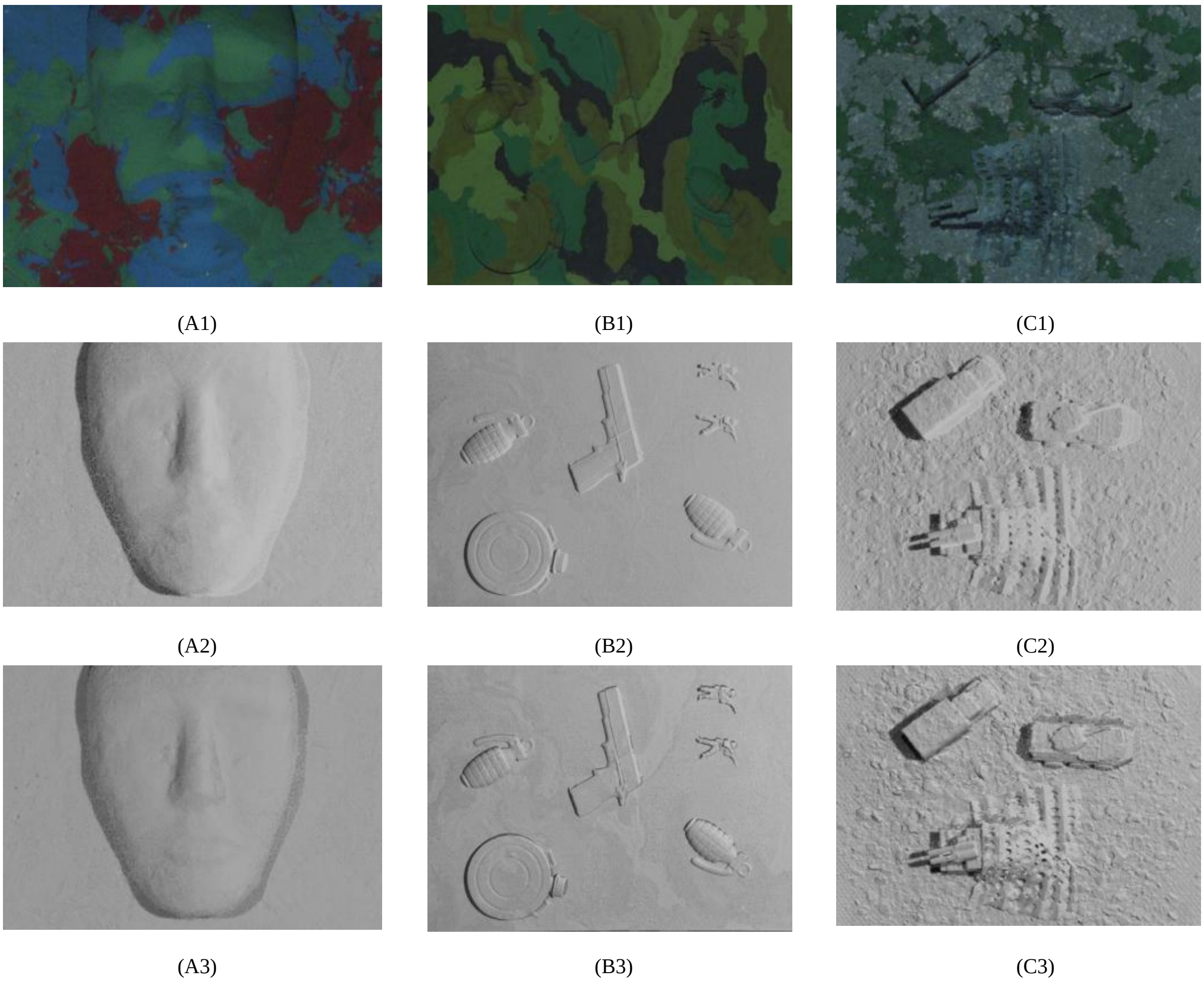
$$\Delta \mathrm{G_x} = |(I_1 + I_2)/l_2^x (I_1)^2| \sigma^2 \tag{9}$$

Therefore, the uncertainty of the system has nothing to do with the location of the first light, which is co-located with the optical axis, as long as l_2^x is not too small

III. Experiments

The effectiveness of the proposed two-light photometric stereo technique is evaluated on several real scenes. The results obtained using conventional three-light photometric stereo are also presented as a reference. The robustness of the two-light photometric stereo in counter camouflage is assessed through varying the lighting from a known position.

The imaging system is built using standard off-the-shelf components, and consists of an AVT Marlin camera (F146C) matched with a compact Schneider XNP 1.4/17 high-resolution lens and three Canon flash guns (430 EX). The targets are static scale models with dimensions of 0.5mx0.4m. The targets are either painted with a camouflage patterns or covered with scaled down camouflage nettings. The background is comprised of flat areas painted with a similar camouflage pattern or contains different artificial foliage to simulate an external environment. The targets and background are usually all painted with similar pattern and colour so that they are blended together, as can been see in Fig. 2 (A1), (B1) and (C1).



Painted face model with a flat background | Heavily painted military toys and flat background | Vehicles and partially occluded toy tank with foliaged background

Fig. 2. Three groups of camouflaged objects (A, B, C) revealed from two- and three-light photometric stereo methods

A. *Effectiveness of Two-light Photometric Stereo*

Three example groups with different foregrounds and backgrounds are used to examine the effectiveness of the proposed strategy to counter camouflage. The first scene consists of a camouflaged face. The second contains various military models including a replica gun, a flask, grenades and toy soldiers. The third scene consists of model tanks and other military vehicles.

The first row of Fig. 2. shows the original raw images as acquired by the camera, which also corresponds that perceived by the human eye. The images show how the camouflage effectively conceals the various objects placed in each scene. The second and third rows are rendered or shaded images obtained from using two- and three-light photometric stereo methods respectively. The results show that both two-light and three-light methods are able to remove the disruptive textures from the surfaces and obtain clean shading pictures of the concealed objects.

It is interesting to note more pigment remaining within the result obtained using the three-light method in Fig. 2 B(3) than that obtained using the two-light method shown in Fig. 2 B(2). This may be caused by the different recovery procedures involved in the two- and three-light methods. Three-light photometric stereo aims to recover both the reflectance and shape information, whereas the two-light method only considers the surface shape information, but cancels out the reflectance information. So a two-light photometric stereo method exhibits good performance in dealing with heavy textures.

B. Robustness to the Location of Lightings

As the estimation of the light position will directly determine the performance in counter camouflage, the following experiment is designed to test the tolerance of the two-light photometric stereo approach to knowledge on the light source positions. This serves to reflect the reality of a practical application in the field. To do this light 1 is fixed to be coincident with the optical axis and light 2 is moved away step by step from its original position by a known distance to the light 1, say δd (in Fig. 3).

The working distance of the system is 150cm and with a starting distance of the second light is 140cm. During each step, two results of counter camouflage will be obtained. One is that recovered by a calibrated correct illuminate position and another is from the incorrectly assumed original position. The error of the location of the second light is expressed with in a absolute value δd or a relative value of $\varepsilon=\delta d/d$.

Two findings can be made from the results shown in Fig. 4. Firstly the performance of two-light source photometric stereo becomes worse as the two lights move closer, but that importantly the system still works reasonably well, i.e. the concealed objects remain clearly discernable, even when the two lights are approaching coincidence. Secondly, the two-light photometric stereo technique is robust to error in the estimation of the direction of light source. It can be found from the right column of the Fig. 4 that the count camouflage technique can produce recognizable results even when the error of the lighting position reaches 21%-43%.

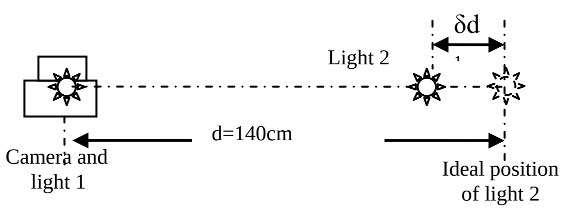
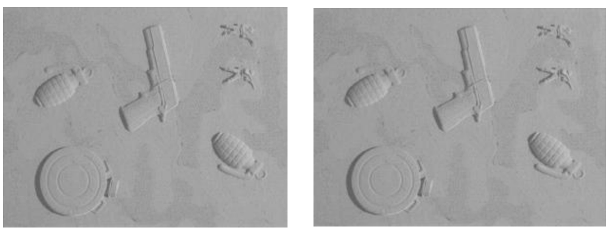
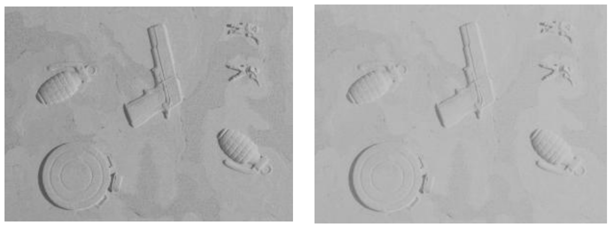


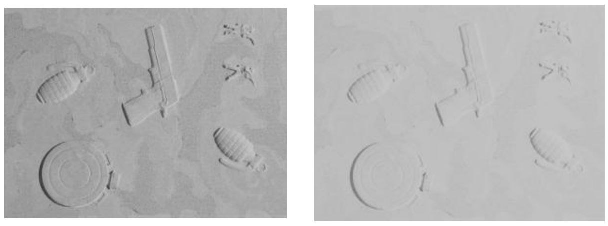
Fig. 3. Changing illumination location to test system robustness



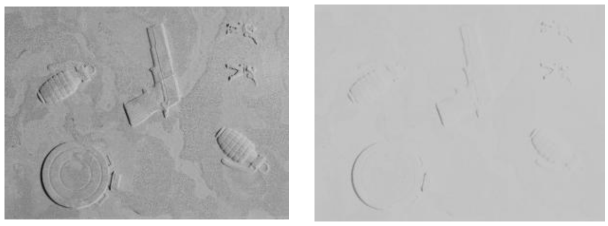
δd =0, ε=0%



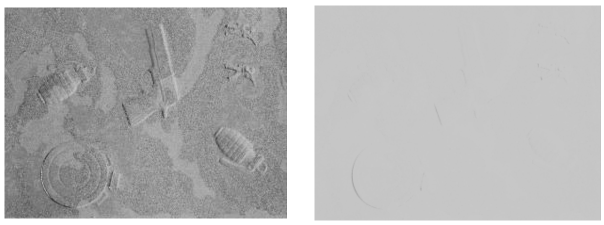
δd =30cm, ε=21%



δd =60cm, ε=43%



δd =90cm, ε=64%



δd =120cm, ε=86%

Fig. 4. Counter camouflage results from the two-light source method. Left are results from using correct incident light directions, the right column are results from a wrongly assumed direction.

IV. Discussion and Conclusions

A new counter camouflage strategy based on a two-light photometric stereo technique has been developed in this paper. The technique can be used to alter a perceived luminance image by cancelling out the reflectance image and rendering clear shaded images thereby removing camouflaging reflectance properties from the surface of concealed objects. The rendered images from the recovered gradient information in only one direction can significantly enhance visibility and help to reveal concealed objects.

Although the technique uses as few as two images, it can achieve a better performance than may be obtained using three or more images - as in conventional photometric stereo. Equipment costs are low, the approach works well for cases involving very complex foreground and background properties and exhibits high robustness with respect to knowledge concerning lighting directions. So the lighting estimation does not need to be as accurate as those used in conventional optical metrology methods. All of these aspects make the implementation of the two-light source photometric stereo method for counter camouflage simple and practical. It has been shown that the illuminates may be located in relative close proximity. The technique therefore lends itself to application as a compact, personal wearable system for operation at close quarters (less that 2m offset) or at a larger scale (over hundreds of meters offset), were the illuminates need to be more widely spaced but where precise illuminate location may and need not be known.

The proposed technique has exhibited promising results in an indoor environment. We intention to design and carry out experiments to investigate application with large scale objects in challenging outdoor environment, where the sun or moon may also be utilized as potential useful light sources.

References

[1] I. C. Cuthill, M. Stevens, J. Sheppard, T. Maddocks, C. A. Parraga, and T. S. Troscianko, "Disruptive coloration and background pattern matching," *Nature*, vol. 434, no. 7029, pp. 72-4, 2005.

[2] M. Sami, T. Juha, and J. Veijo, "Optimization of cryptic coloration in heterogeneous habitats," *Biological Journal of the Linnean Society*, vol. 67, no. 2, pp. 151 – 161.

[3] M. T. Eismann, C. R. Schwartz, J. N. C. Amd, and R. J. Huppi, "Comparison of infrared imaging hyperspectral sensors for military target detection applications," in *Proc. SPIE – Int. Soc. Opt. Eng.*, 1996, vol. 2819, pp. 91–101.

[4] H. Wendy, B. Gary, G. Trevor, H. Daniel, and I. Greg, "Multispectral-polarimetric sensing for detection of difficult targets," in *Proc. SPIE*, 2008, vol. 71, pp. 13-22.

[5] A. Tankus and Y. Yeshurun, "A model for visual camouflage breaking," *IEEE International Workshop on Biologically Motivated Computer Vision*, 2000, pp. 139-149.

[6] N. U. Bhajantri and P. Nagabhushan, "Camouflage defect identification: a novel approach," in *Proc. of 9th International Conference on Computer and Information Technology*, 2006, pp. 99-101.

[7] Z. Q. Huang and Z. Jiang, "Tracking camouflaged objects with weighted region consolidation," in *Proceedings of Digital Image Computing: Techniques and Application*, 2005, pp. 161-168.

[8] B. K. P. Horn, "Determining lightness from an image," *Computer Graphics and Image Processing*, 1974, vol. 3, no. 1, pp. 277-299.

[9] J. Sun, M. L. Smith, L. N. Smith, P. S. Midha, and J. C. Bamber, "Object surface recovery using a multi-light photometric stereo technique for non-Lambertian surfaces subject to shadows and specularities," *Image and Vision Computing*, 2007, vol. 25, no. 7, pp. 1050-1057.

[10] E. H. Adelson and A. P. Pentland, "The perception of shading and reflectance," *Perception as Bayesian Inference*, New York: Cambridge University Press, 1996, pp. 409-423.

[11] R. Zhang, P. S. Tsai, E. C. James, and S. Mubarak, "Shape from shading: a survey," *IEEE Trans. Pattern Anal. Mach. Intell.*, 1999, vol. 21, no. 8, pp. 690-706

[12] R. J. Woodham, "Photometric method for determining surface orientation from multiple images," *Optical Engineering*, vol. 19, no. 1, pp. 139-144, 1980.

J. Sun is a Research Fellow in Machine Vision at UWE. He joined the Machine Vision Laboratory in 2003, where he commenced work on a DPhil which he completed in 2007. His work was based on the fundamental methodology of photometric stereo and its application to skin surface inspection. He also holds a PhD in Biomedical Engineering from Shanghai Jiaotong University, China. His interests are broad and include electronics, optics and computing techniques applicable to healthcare and industry. Currently, his work mainly concerns genuine recovery methods on skin conditions for purposes ranging from dermatology to cosmetics.

M. L. Smith is a Professor of Machine Vision at the Bristol Institute of Technology and director of the Machine Vision Laboratory at UWE. He received his PhD in 1997, MSc in 1988 and BEng in 1987. He acts as an Associate Editor for four leading international journals, including Image and Vision Computing and Computers in Industry and is a program committee member for two international conferences. He regularly presents his work through invited seminars, as well as articles and interviews to the popular media. He has been a member of the EPSRC Peer Review College since 2003, served as European Commission candidate evaluator for the Sixth Framework and is currently a programme and evaluator/review expert and monitoring expert for EU framework seven programmes. He is a Chartered Engineer and an active member of the IET.

A. R. Farooq is a Post-Doctoral Research Fellow and a Visiting Lecturer in the Machine Vision Laboratory at the UWE. His research is focused on developing new vision-based techniques for the inspection of complex surfaces in real time. He graduated from University in 1990 with a first degree in Electronics and subsequently successfully completed an MSc in Systems Engineering (Robotics and Automation) in 1992. He then worked for a number of years as a Systems Engineer at a leading edge high-volume board manufacturing plant. His role involved elements of R&D, troubleshooting and PLC programming. Following this, A.R. Farooq was drawn back to academia and completed (with distinction) a further Masters degree followed by a successful PhD involving machine vision. A.R. Farooq has been involved with a number of successful projects within the group and currently manages a TSB-funded project related to application of photometric stereo in dermatology. A.R. Farooq's areas of expertise include instrumentation, design and development of medical imaging devices; and he is also a member of the IET and a Chartered Engineer.

L. N. Smith is a reader in Computer Simulation and Machine Vision and Co-director of the Machine Vision Laboratory at University of the West of England (UWE). Following his BSc (Hons) in Physics in 1986, he obtained an MSc in Manufacturing in 1988 and PhD in Engineering in 1997. In 1998 and 1999, he was the Director of Computer Simulation at a Research Laboratory in the Engineering Science & Mechanics Department at The Pennsylvania State University in the USA. L.N. Smith has achieved simulation and modeling of complex 3D forms through employment of techniques that have ranged from multivariate analysis through to NNs. He also developed a new technique for analysis of complex irregular morphologies, which employed a combination of machine vision analysis and stochastic 3D shape simulations. His research activities have resulted in the publication of over 110 technical papers and a book, as well as frequent refereeing of journal papers and the chairing of international research conferences in the USA and Europe.