Enhancing stereo matching performance by colour normalisation and specularity removal

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A method to enhance the performance of stereo matching is presented. The position of the specular light reflection on an object surface varies due to the change in the position of the camera, light source, object or all combined. Additionally, there may be situations exhibiting a colour shift owing to a change in the light source chromaticity or camera white balance settings. These variations cause misleading results when stereo matching algorithms are applied. In this reported work, a single-image-based statistical method is used to normalise source images. This process effectively eliminates non-saturated specularities regardless of their positions on the object. The effect of specularity removal is tested on stereo image pairs.

Introduction: Stereo matching is an active research area and a vast number of algorithms for finding correspondences in multi-frame images have been presented. A comprehensive performance analysis of these methods is given by Sharstein and Szeliski [1].

The main goal of stereo methods is to generate a disparity map from image pairs. Specular reflections, especially in cases where the position of the specular reflection changes drastically, cause unwanted results. This position change is mostly due to a change in the relative orientation of the object surface with respect to the camera. The light source position may also change independently.

In [2], a stereo-enhanced colour processing method which deals with the unwanted effect of specular variations on surfaces is given by Lin *et al*. This method uses an image sequence to remove specularity with a strict assumption that all scene points present diffuse reflection in at least one of the views.

In [3], Bhat and Nayar embedded a physically based model of reflected light into a stereo matching method to obtain a better stereo matching result in the specular regions of images, but their analysis required controlled lighting conditions and fully calibrated camera positions.

In this Letter, the proposed method does not have restrictive assumptions. Furthermore, it does not require a complicated experimental setup. The only assumption in the method proposed is that the pixel values in the images are not saturated. This assumption holds in most cases where exposure settings avoid saturation and objects do not contain mirror-like highly reflective parts.

Proposed method: The light reflection from surfaces of semi-glossy materials can be represented by the dichromatic reflection model, which implies that reflected light is a linear combination of both diffuse and specular components. In (1), I_c is a pixel with the intensity value of the colour channel c (i.e. red, green or blue). m_d and m_s are diffuse and specular reflection coefficients; Λ and Γ are diffuse and specular chromaticities, respectively.

$$I_c = m_d \Lambda_c + m_s \Gamma_c \tag{1}$$

In [4], we presented a method which can determine the illuminant chromaticity (Γ) by using the dichromatic reflection model and inverse-intensity ($1/\sum I_i$, where $\sum I_i = I_R + I_G + I_B$) chromaticity ($\sigma$) space (IICS), introduced in [5]. By applying chromaticity definitions and algebra, (1) can be rearranged as (2) (for further detail see [5]). In this equation σ_c is the image chromaticity which can be calculated for the colour channel c as $\sigma_c = I_c/\sum I_i$:

$$\sigma_c = p\frac{1}{\Sigma I_i} + \Gamma_c \tag{2}$$

Here, $p = m_d(\Lambda_c - \Gamma_c)$. As shown in [5], if the pixels from the specular reflection regions are selected and shown in IICS, intersections of straight lines passing from these points are concentrated at one point on the chromaticity axis, and this point is the specular chromaticity Γ_c of the corresponding colour channel. In [4], first the pixels of the specular region are selected roughly by thresholding the S and I components of HSI colour space. If a candidate point from the chromaticity axis is taken (consider it to be Γ'), and every single line drawn from data points in IICS to Γ' is considered, (some of these lines are shown for two Γ' values on the blue channel chromaticity axis, 0.10 and 0.55, in Fig. 1*a*), the normalised distributions of their slopes can be calculated and plotted as in Figs. 1*b* and *c*. Using (2), the slopes are interpreted as p values. The distribution given in Fig. 1*b* corresponds to the situation in which Γ' is taken as 0.10; similarly the distribution in Fig. 1*c* corresponds to the situation in which Γ' is taken as 0.55. The latter value is very close to actual blue channel chromaticity of the light source measured by using a white reference card. For this distribution in Fig. 1*c*, as can also be intuitively deduced from the representation in Fig. 1*a*, the distribution is more densely distributed in a smaller interval of p values compared to the former one. Furthermore, if the standard deviations of the distributions for $\Gamma' \in [0.0\ 1.0]$ are considered and plotted, Fig. 1*d* is obtained. It is found that the global maximum of this plot gives a good estimate for the specular chromaticity of the corresponding colour channel (Γ_c^{est}).

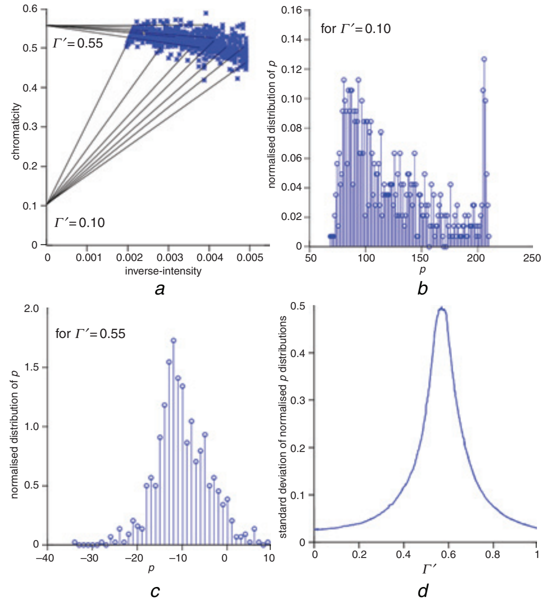

Fig. 1 *Pixels selected from specular areas of Fig. 2d shown in IICS for blue channel. Grey lines are some of the lines from sample points to specular chromaticity candidate values $\Gamma' = 0.10$ and $\Gamma' = 0.55$ (Fig. 1a); normalised distribution of p values for $\Gamma' = 0.10$ (Fig. 1b); normalised distribution of p values for $\Gamma' = 0.55$ (Fig. 1c); standard deviation of the normalised p distributions for $\Gamma' \in [0.0\ 1.0]$*

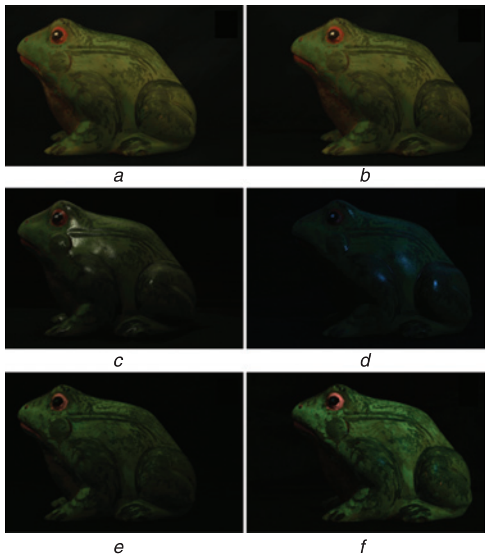

Fig. 2 *Stereo image pair captured in homogeneously illuminated soft box (Figs. 2a, b); stereo image pair with apparent specular reflections and different illuminant colours (Figs. 2c, d); specular-free versions of Figs. 2c and d, respectively*

For display purposes, brightness values of images are normalised such that darkest point becomes black and brightest point becomes brighter without changing hue (Figs. 2*e*, *f*)

By using estimated scene illuminant chromaticity, corresponding images can be normalised as in (3) so that the specular chromaticity becomes $\Gamma^n = [1/3, 1/3, 1/3]'$:

$$I^n = \frac{I}{\Gamma^{est}} = m_d^n \Lambda^n + m_s^n \Gamma^n \quad (3)$$

Once the images are normalised, it is possible to obtain specular-free versions of them. As suggested in [6], (4) can be applied to three colour channels separately to obtain a specular-free image ($\tilde{\boldsymbol{I}}$):

$$\tilde{I}_c = I_c^n - \min(I_R^n, I_G^n, I_B^n) \quad (4)$$

Since variations in light source position and colour causes unwanted results in depth recovery from stereo image pairs, the above method can be used as a preprocessing step for stereo matching algorithms. In this study, experiments have shown that, if the specular reflections are removed from images, stereo matching performance is significantly enhanced.

Results: In order to present the enhancement in stereo matching performance, a reference stereo image pair (Figs. 2*a* and *b*) is used. These images are captured in a homogeneously illuminated soft box. There is no significant specular reflection from the object surface. When this image pair is used in a normalised cross-correlation-based stereo matching algorithm (see [1] for further details), a depth image (Fig. 3*a*) is obtained. This image is considered as a reference case that can be used to measure the success of the proposed algorithm.

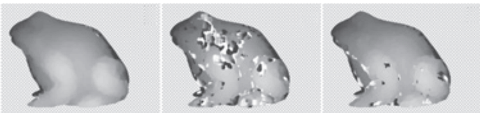

Fig. 3 *Ideal case depth image generated using stereo pair shown in Figs. 2a and b (Fig. 3a); depth image generated using stereo pair shown in Figs. 2c and d 'PSNR wrt. Fig. 3a' = 19.24 dB (Fig. 3b); enhanced depth image generated using stereo pair shown in Figs. 2e and f 'PSNR wrt. Fig. 3a' = 24.65 dB (Fig. 3c)*

Another image pair is given in Figs. 2*c* and *d*. Unlike the previous pair, specular reflections can be seen in the images. Moreover, the dominant wavelength of the light source in Fig. 2*c* is different to that of the light source in Fig. 2*d*. This causes an apparent shift in hue. The stereo matching algorithm was directly applied to these images, and Fig. 3*b* shows the resultant depth image. As can be seen from this Figure, estimated depth values are significantly distorted.

When the colour normalisation and specularity removal operations are applied to Figs. 2*c* and *d*, Figs. 2*e* and *f* are obtained. The stereo matching algorithm was applied to this specular-free image pair, and the resulting depth image is shown in Fig. 3*c*. When Figs. 3*b* and *c* are compared, the improvement can be clearly seen.

Conclusion: In this Letter a new method to enhance the performance of stereo matching algorithms is given. The main focus is on alleviating the problems caused by specular reflections and change in light source chromaticity. Normalising images and removing specularity after light source chromaticity estimation enhances the performance of stereo matching algorithms significantly. The proposed method successfully removes specularities in stereo image pairs. Since the method is applied to each image independently, specular regions which appear on different parts of the source images are handled successfully. As can be seen from Fig. 3*c*, the total size of the regions with false depth values is reduced significantly. Remaining artefacts are mostly due to the reduction in dynamic range while generating specular-free images and intensity variations caused by the change in light source position. Adapting the proposed method to high dynamic range images can further enhance the result.

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One or more of the Figures in this Letter are available in colour online.

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References

1 Sharstein, D., and Szeliski, R.: 'A taxonomy and evaluation of dense two-frame stereo correspondence algorithms', *Int. J. Comput. Vis.*, 2002, **47**, pp. 7–42
2 Lin, S., Yuanzhen, L., Kang, S.B., Tong, X., and Shum, H.: 'Diffuse-specular separation and depth recovery from image sequences'. Proc. European Conf. on Computer Vision, (ECCV), Copenhagen, Denmark, 2002, pp. 210–224
3 Bhat, D.N., and Nayar, S.K.: 'Stereo and specular reflection', *In. J. Comput. Vis.*, 1998, **26**, pp. 91–106
4 Ozan, Ş., and Gümüştekin, Ş.: 'Estimation of scene illuminant chromaticity by using single image'. Proc. 19th IEEE Conf. Signal Processing and Communication Applications (SIU2011), Ankara, Turkey, 2011
5 Tan, R.T., Nishino, K., and Ikeuchi, K.: 'Illumination chromaticity estimation using inverse-intensity chromaticity space'. IEEE Computer Society Conf. on Computer Vision and Pattern Recognition, Madison, MI, USA, 2003, Vol. 1, pp. 673–680
6 Shen, H.L., Zhang, H.G., Shao, S.J., and Xin, J.H.: 'Chromaticity-based separation of reflection components in a single image', *Pattern Recognit.*, 2008, **41**, (8), pp. 2461–2469