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Underwater Image Pre-Processing for Photogrammetric Application

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***Abstract* – This work describes a new method for correcting underwater images acquired under natural illumination condition and targeted to photogrammetry for 3D object reconstruction. In particular, a comparison between the new approach and a previous one from literature is presented. The new approach demonstrated to be a feasible and robust solution to improve quality, colour and contrast in underwater imaging by means of a three-step procedure. The focus of the paper is on 3D reconstruction of small-sized corals in shallow water. The colour of pre-processed images, with a visible green-blue colour cast, are enhanced and the higher images quality eases the whole object reconstruction acquired in a poor visible scene. The higher performance of the proposed method is experimentally demonstrated.**

I. INTRODUCTION

Pre-processing of underwater images is widely used for improving habitats monitoring and species detection and recognition [1, 2] This is because images taken in underwater environment are affected by degradation due to limited range of visibility, low contrast, non-uniform light illumination and blurring. The main reason of quality loss is light attenuation depending on water absorption, which reduces the colour information, and scattering effects, caused by the different media at the air-water interface, which involves blur and distance reduction around 25% of the acquired image size.

Imaging systems are therefore badly affected by these phenomena.

However, the possibility to reconstruct colour and 3D shape of marine organisms as those populating the coral reef environment is important for marine biologists. Indeed, this digitalization of the environment makes it possible to monitor the growth and the health state of these organisms. The most common and cheap solution that provides both colour and shape data is underwater photogrammetry [3].

In the frame of this work, photogrammetry is adopted for digitizing an individual coral in shallow water (<1 m). No artificial light is used, partially because of the low depth of the coral and to demonstrate that natural illumination issues, bringing non-uniform light on the scene, can be overcome with a proper use of colour correction algorithms. In fact, it is demonstrated that the proposed colour correction approach is able to enhance the quality of the acquired images and consequently ease features extraction in the next photogrammetric process.

The main contribution of this work is to compare results with a previous approach from literature, in order to prove the higher performances of the former.

A. State of the art

From the several methods presented in literature for colour correction of underwater scenes, it is possible to distinguish two different categories. Those methods trying to restore image quality by adopting physics-based approaches [4, 5] or polarization filters [6, 7] belong to the first category. Omethods enhances image quality by means of qualitative criteria, without a priori knowledge of the environment.

In the first case, some physical models require calibrating the necessary parameters in the local water body, such as attenuation or scattering coefficients [8] or, in other cases, it is possible to inaccurately estimate light transmission because a uniform illumination is assumed.

For what image enhancement techniques are concerned, some works improve the contrast and the brightness by using homomorphic filtering [9, 10, 11, 12] or the Integrated Colour Model (ICM) and the Unsupervised Color Correction Method (UCM) [13, 14, 15]. The Contrast Limited Adaptive Histogram Equalization (CLAHE) algorithm [16] is a method widely used to improve contrast of underwater images [17] and videos [18]. However, all the techniques mentioned increase the overall contrast performances without improving colour quality; moreover, the blue-green colour cast is retained.

To decrease the aquatic colour cast and return the correct colours of the scene, the previous approaches are combined with computational colour constancy approaches, as Grey-World assumption [19, 20] and White Balance algorithm [18].

The aim of this work is to demonstrate the higher efficiency of the proposed method for colour correction, compared to the colour correction process proposed by Tan [20]. The difference between the two methods is mainly the introduction of a gamma correction step, which reduces the brightness distortion, making illumination of the dataset uniform. The utility of this approach is proved in 3D reconstruction by the match of images with local feature points. The error of nine Ground Control Points (GCPs) properly selected on the 3D models obtained by means of the two different approaches is estimated.

II. MATERIALS AND METHOD

Images of the coral used for this paper were acquired at Magoodhoo Island site (Maldives). The coral reported was chosen for its colour and complex structure. A set of 37 photos in random positions were shot in shallow water at a depth of about 2 m. A white reference target and a ruler were placed close to the coral and framed in all the acquired images to ease colour correction and the next shape reconstruction.

A Nikon D5600 camera body (sensor resolution: 24.2 MP, 'full frame' sensor size) equipped with a zoom lens (AF-S with 18-105 mm) was exploited in the shooting campaign. Both camera body and lens were confined in an underwater housing with a "dome port".

Fig. 1. Acquisition site

A. Colour correction method

The proposed approach is characterized by a three-step procedure: a) contrast enhancement, b) correction of colour intensity that partially removes the green-blue colour cast, c) adjustment of brightness by a modification of the *gamma* value, which maps the luminance levels.

It is important to notice that the first step operates in L*a*b* colour space, in order to work only on the luminance channel (L*), without changing the intensity values (a*b*) [21].

After the contrast adjustment step, the colour balance of RGB channels is applied by using the white target as reference colour patch. The main goal of this second step is to render correctly the neutral colours (white, grey and black) by changing the overall mixture of colours in the images.

Finally, the gamma correction is the last step used to encode linear luminance and to correctly quantify the brightness.

B. Evaluation of the 3D models

After the colour correction step, the images acquired were processed using the commercial software Photoscan. This made it possible to run a photogrammetric 3D reconstruction of the coral.

A set of nine Ground Control Points (GCPs) selected on the ruler was exploited to evaluate the performamce of the of the Structure from Motion (SfM) approach adopted.

C. 3D models comparison

In order to assess the efficiency of the corrected images in 3D reconstruction, the comparison between the different points clouds is reported (Fig. 5). The distances between points are obtained by means of the Multiscale Model to Model Cloud Comparison (M3C2) algorithm [22], which is available in the CloudCompare software. This algorithm performs the average distance between the point clouds along surface normal and the distance uncertainty based on Level of Change Detection ($LOD_{95\%}$). In this way, it is possible to represent the displacement change of the different 3D models obtained by colour corrected images with respect to the ones obtained using the uncorrected raw data.

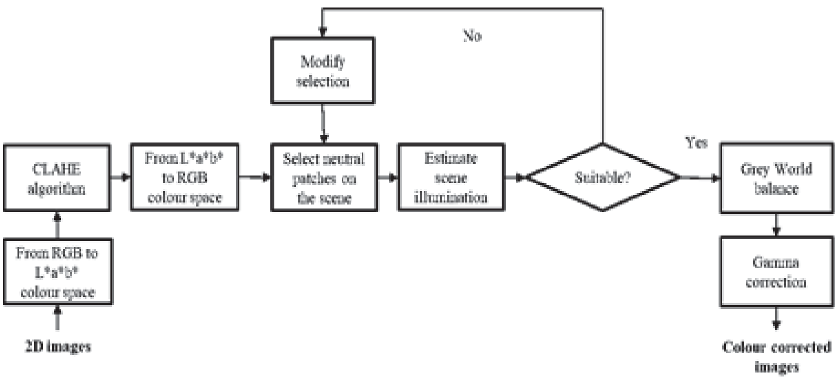


Fig. 2. Block diagram of the proposed method.

III. RESULTS AND DISCUSSION

A. Visual assessment of colour corrected images

The qualitative results show the colour corrected images obtained by means of the proposed approach and compared with the method proposed by Tan [20]. From visual inspection (Fig. 3), it is possible to see that both the methods balance the colours of the scene, but the main difference is on the luminance restoration, which is notice only on the processed images by means of the proposed method.

This means that the images corrected by the previous method have lower intensity values and the scene appears darker and without the correct illumination. This is an important issue to be considered, mainly when there is the necessity to work in weak and non-uniform lighting conditions.

(a)

(b)

(c)

Fig. 3. Example of some unprocessed underwater images (a) compared to the colour corrected images respectively by means of the previous (b) and the proposed (c) method.

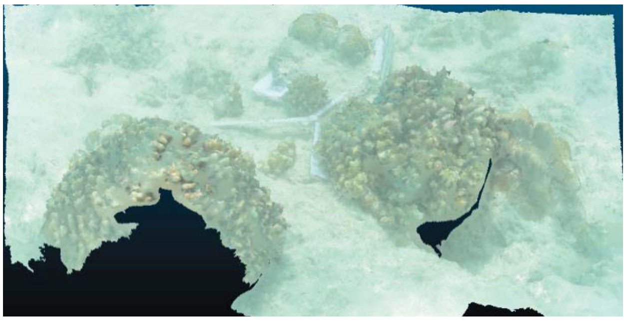
B. Qualitative results of 3D models

From the visual assessment of the reconstructed 3D models, it is possible to see that both the set of colour corrected images provide more accurate and detailed structures (Fig. 4, c) compared to the one obtained by the unprocessed images (Fig. 4, b).

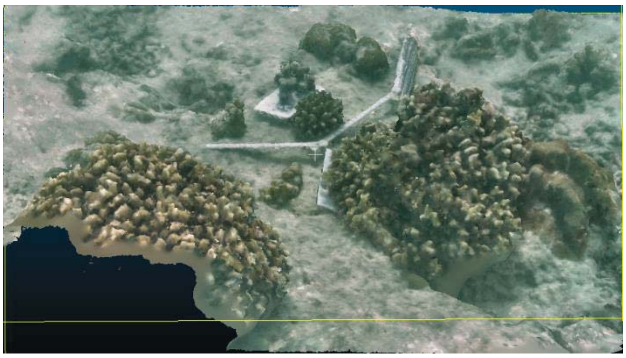
The error between the reference and the estimated GCPs are reported in Table 1. The total error on the models obtained for both the set of pre-processed images is less than that obtained by using the unprocessed images.

Table 1. Summary of GCPs position and scaling errors

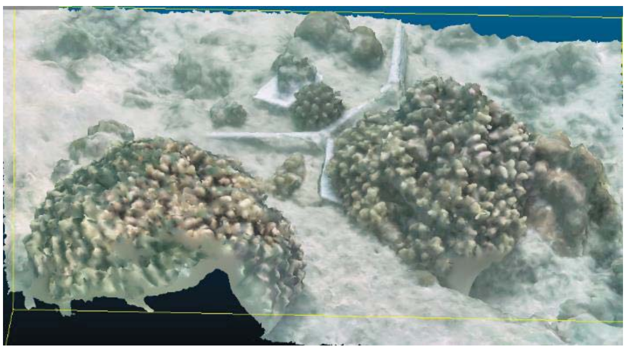
	X_{error} (mm)	Y_{error} (mm)	Z_{error} (mm)	Total (mm)	D_{error} (mm)
Raw dataset	1.44	0.95	1.78	**2.48**	**1.60**
Method in literature	0.20	0.19	0.30	**041**	**0.31**
Proposed method	0.30	0.46	0.45	**0.65**	**0.34**



(a)



(b)



(c)

Fig. 4. 3D models obtained by original (a) and pre-processed images by previous method (b) and proposed approach (c).

C. 3D models comparison results

Results of the M3C2 comparison show the significant change between the different reconstructed 3D models. The red colour portion highlights the positive values of significant changes, while the blue colour portions are the negative values and the grey colour corresponds to insignificant change because of lack of information.

The analysis is performed on the models obtained from original (C_1) and corrected images (namely C_2 for the images corrected with the proposed method and C_3 for the images corrected with the Tan method). The C_1 dataset is considered as the reference point cloud.

In Fig. 5, the significant changes along all orientations are shown. When comparing C2 vs C1 (Fig. 5,a) and C3 vs C1 (Fig. 5,b), a significant deviation can be noted on the bottom left part of the plot. Contrarily, when comparing C2 vs C3, i.e. the point clouds from the corrected images, the deviations are significantly small (Fig. 5, c).

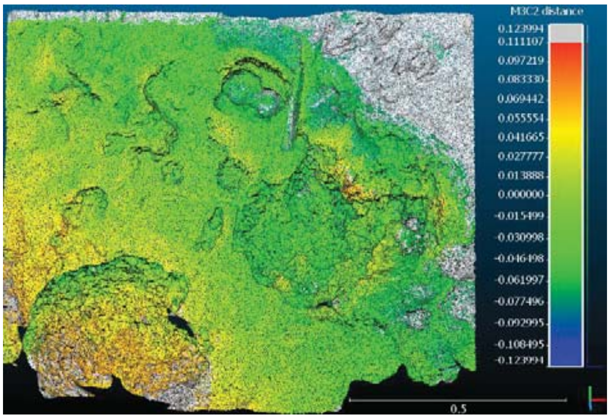
The results of this analysis are presented along X-, Y- and Z-axes and summarized in Table 2. The significant changes are observed mainly on the Z-axis between the corrected clouds (C_2 and C_3) and the original one (C_1).

In particular, the mean distance measured on vertical direction between C2 - C1 (4.9 ± 35 mm) and C3 - C1 (4.5 ± 36 mm) demonstrate that the model obtained by original images has a more flattened volume than the other two models.

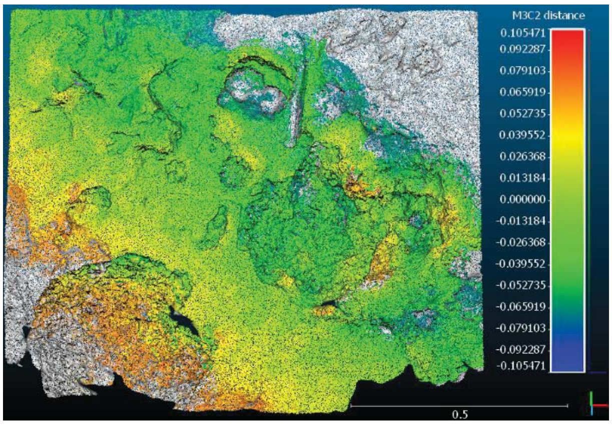
Contrarily, the comparison between the 3D models obtained applying both the previous and the proposed method for correcting colour of images (C3 – C2) shows negligible changes in all the three directions. In particular, on the Z-axis the mean distance between the two models is 0.004 ± 20 mm.

Table 2. Summary of mean and standard deviation along the X, Y, Z coordinates

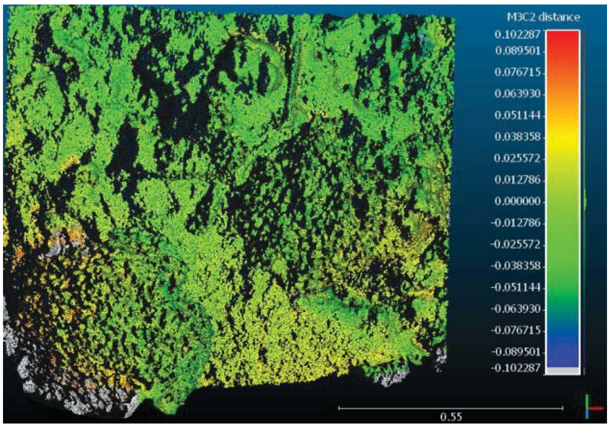
		C2-C1	C3-C1	C3-C2
X-axis	*Mean (mm)*	1.5	-1.8	0.4
	SD (mm)	37	38	20
Y-axis	*Mean (mm)*	3.4	3.1	1.5
	SD (mm)	37	38	20
Z-axis	*Mean (mm)*	4.9	4.5	0.04
	SD (mm)	35	36	20



(a)



(b)



(c)

Fig. 5. M3C2 results obtained by the comparison between: (a) C_2 and C_1, (b) C_3 and C_1, (c) C_2 and C_3.

IV. CONCLUSION

The proposed method for colour correction of underwater images is able to render a 3D model characterized by high details, balanced colours and corrected illumination. It is a valuable solution for enhance the quality of a scene captured in underwater environment.

Compared to the approach proposed by Tan, it is possible to notice that both methods returns accurate 3D models. However, the proposed algorithm provides more realistic colours and illumination.

REFERENCES

[1] P. X. Huang, B. J. Boom and R. B. Fisher, "Underwater Live Fish Recognition Using a Balance-Guaranteed Optimized Tree," *Asian Conference on Computer Vision,* pp. 422-433, 2012.

[2] D. J. Lee, R. B. Schoenberger, S. D., X. Xu and P. Zhan, "Contour Matching for Fish Species Recognition and Migration Monitoring," *Two-and Three-Dimensional Vision Systems for Inspection, Control, and Metrology II,* vol. 5606, pp. 37-49, 2004.

[3] J. X. Leon, C. M. Roelfsema, M. I. Saunders and S. R. Phinn, "Measuring coral reef terrain roughness using 'Structure-from-Motion'close-range photogrammetry.," *Geomorphology,* vol. 242, pp. 21-28, 2015.

[4] J. Åhlén, "Colour correction of underwater images using spectral data," *Doctoral dissertation, Acta Universitatis Upsaliensis,* 2005.

[5] J. S. Jaffe, "Computer modeling and the design of optimal underwater imaging systems," *IEEE Journal of Oceanic Engineering,,* vol. 15, pp. 101-111, 1990.

[6] Y. Y. S. a. N. Karpel., "Clear underwater vision," *Proc. IEEE Computer Society Conference on Computer Vision and Pattern Recognition,* vol. 1, pp. 536-543, 2004.

[7] Y. Y. Schechner and N. Karpel., " Recovery of underwater visibility and structure by polarization analysis," *IEEE Journal of Oceanic Engineering,* vol. 30, pp. 570-587, 2005.

[8] C. O. Ancuti, C. Ancuti, C. De Vleeschouwer and R. Garcia, "Locally Adaptive Color Correction for Underwater Image Dehazing and Matching.," *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition Workshops ,* pp. 1-9, 2017.

[9] S. Bazeille, I. Quidu, L. Jaulin and J. P. .. I. (. x. Malkasse, "Automatic underwater image pre-processing," *CMM'06,* 2006.

[10] T. N. R. Garcia and X. Cufi, "On the way to solve lighting problems in underwater imaging," *Proceedings of the IEEE Oceans Conference Record,* vol. 2, pp. 1018-1024, 2002.

[11] M. Borgetto, V. Rigaud and J. F. Lots, "Lighting correction for underwater mosaicking enhancement," *Proceedings of the 16th International Conference on Vision Interface,* 2003.

[12] C. J. Prabhakar and P. U. Kumar, " An image based technique for enhancement of underwater images," *arXiv preprint arXiv,* 2012.

[13] K. Iqbal, R. A. Salam, A. Osman and A. Z. Talib, "Underwater Image Enhancement Using an Integrated Colour Model," *AENG International Journal of Computer Science,* vol. 34, 2007.

[14] K. Iqbal, M. O. Odetayo, A. E. James, R. A. Salam and A. Z. Talib, "Enhancing the low quality images using Unsupervised Colour Correction Method," *SMC ,* pp. 1703-1709, 2010.

[15] A. S. A. Ghani and N. A. M. Isa, "Underwater image quality enhancement through Rayleigh-stretching and averaging image planes," *International Journal of Naval Architecture and Ocean Engineering,* vol. 6, pp. 840-866, 2014.

[16] K. Zuiderveld, "Contrast Limited Adaptive Histograph Equalization," *Graphic Gems IV,* p. 474–485, 1994.

[17] W. Yussof, M. Hitam, E. Awalludin and Z. P. Bachok, "Performing contrast limited adaptive histogram equalization technique on combined color models for underwater image enhancement.," *Int. J. Interact. Digit. Media. ,* 2013.

[18] G. Bianco, M. Muzzupappa, F. Bruno, R. Garcia and L. Neumann, "A new color correction method for underwater imaging," *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences,* 2015.

[19] G. Buchsbaum, " A spatial processor model for object colour perception.," *Journal of The Franklin Institute-engineering and Applied.,* 1980.

[20] C. S. Tan, P. Y. Lau, M. C. Lim, J. A. Hi, E. P. Lim, S. M. Phang and T. J. Low, "An Effective Approach for the Underwater Color Image Enhancement.".

[21] S. Bharal, "L* a* b based contrast limited adaptive histogram equalization for underwater images," *Int J Comput Appl, ,* 2015.

[22] D. Lague, N. Brodu and J. Leroux, " Accurate 3D comparison of complex topography with terrestrial laser scanner:Application to the Rangitikei canyon (N-Z).," *ISPRS J. Photogramm.,* 2013.