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Design of Experiments to evaluate the main influential factors affecting underwater photogrammetric 3D reconstructions

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***Abstract* – In this paper the Design of Experiments approach is employed to determine the effects of some of the main influential factors on the photogrammetric 3D reconstruction process applied in an underwater environment. A variational analysis of some factors that influence the quality of the 3D reconstruction, such as image resolution and colour channels, has been performed. This statistical analysis allowed for finding an optimal combination of factors to be used in the 3D reconstruction process, providing a series of guidelines for a complete and accurate modeling of a submerged site.**

I. INTRODUCTION

Among the 3D imaging techniques suitable for underwater applications, the photogrammetric 3D reconstruction represents a valid solution to reconstruct 3D scenes from a set of images taken from different view-points [1]. Anyway, image-based acquisition suffers from critical environment conditions caused by several factors like depth and turbidity of the water that reduce the visibility and alter colours.

For this purpose, an experimental campaign has been carried out, on the basis of the DoE (Design of Experiments) [2] method, in order to identify the most relevant factors that affect the underwater reconstruction process. This work focuses on the camera orientation and calibration phases, using a SFM (Structure from Motion) algorithm that works on the points of interest evaluated by a feature extraction and matching algorithm. The results are assessed using image quality as the main parameter, for this reason the effect of four image pre-processing algorithms has been investigated through a statistical approach. The purpose of this analysis is to evaluate, on a statistical basis, if a factor or a combination of factors have an influence on a parameter with a certain confidence level, in order to find the best combination of factors which will be used to create the 3D reconstruction of the submerged site.

The experimentation has been conducted at the archaeological site of Baiae located few kilometers north of Naples (Italy). The submerged archeological park of Baiae is characterized by bad visibility conditions, due to water turbidity and heavy presence of flora and fauna. The complete dataset acquired in the experimentation activity includes a total of about 700 images.

II. DESIGN OF THE EXPERIMENTAL CAMPAIGN

In the first step of the DoE campaign the influencing factors that cause a variation in the parameters have been selected (tab 1).

Table 1. Influence factors and related levels used to perform the analysis of variance.

Influence factor	Level	Symbol
Colour enhancement method	OR, WB, HIST, ACE, PCA	EN
Image pyramid level	1, 2, 3	PYR
Colour channel	RGB, R, G, B	CH
Image set	SET 1, 2, ..., 7	SET

The first factor is the colour enhancement algorithm used to improve the underwater images (EN). In this experimentation, the original images have been compared with the ones corrected using four different methods: a) the ACE (Automatic Colour Enhancement) [3], b) the PCA (Principal Component Analysis) [4], c) an algorithm based on *in situ* white balance measure (WB), d) a custom method based on the Histogram Stretching (HIST) [5].

The second factor is represented by the image resolution (PYR). An image pyramid has been created, so the levels of this factor correspond to the pyramid levels: at the first level (PYR = 1) the images are halved (4 times less pixels), at the second level (PYR = 2) the images are 4 time smaller (16 times less pixels) and at the third pyramid level (PYR = 3) the images contain 64 times less pixels.

The third factor is represented by the colour channel used for the 3D reconstruction. The levels of this factor are the three components R (Red), G (Green) and B (Blue) and the composite RGB image.

In order to perform a quantitative analysis of the influence of the camera layout on the processing results, the type of image set (SET) was included as an influencing factor in the variational analysis. Seven subsets have been created, which differ among each other by the type of shot (aerial vs. oblique), working distance, and pictures overlapping.

Then the parameters of interest have been identified, e.g. the number of extracted features and the number of oriented cameras. The first parameter has been evaluated by using the SIFT (Scale Invariant Feature Transform) operator. The other parameters (percentage of oriented cameras, percentage of matched features and the bundle adjustment mean re-projection error), have been evaluated using Bundler. In order to perform the statistical analysis, 196 images belonging to the seven image sets have been extracted from the whole dataset. First, the three colour enhancement methods (ACE, PCA, WB, HIST) have been applied on the original, full resolution images. Then the images have been resized according to the pyramid levels. The collected data have been processed with an analysis of variance technique (ANOVA) and well-known statistical tools.

III. RESULTS AND CONCLUSIONS

Since different factors affect the 3D reconstruction process, the DoE approach has been adopted to determine the most influential ones. Three different colour enhancement methods, i.e., ACE, PCA and HIST, have been compared and evaluated by using a dataset of images acquired in the underwater archaeological park of Baiae.

These image enhancement algorithms have been compared by means of the analysis of the variance (ANOVA), including the effects of image resolution and colour channel. The analysis of variance has been conducted using the Matlab Statistical toolbox, in particular a multiway (n-way) analysis of variance has been performed by testing the effects of multiple factors on the mean of the values of the current parameter.

ANOVA results show, with a confidence level of 95%, that EN (Image enhancement method), PYR (Image pyramid level) and SET (Image set) factors affect the reconstruction process. On the contrary, the CH (Colour channel) factor has a limited influence.

The results suggest the best combination of factors to optimize the SfM bundle adjustment mean re-projection error, the number of extracted features, oriented cameras and matched features. More precisely, the best combination is characterized by RGB images, resized to 25%, and enhanced with the HIST method, that has shown more stable results.

By using the results of the statistical analysis to correct and process the underwater images, it has been possible to align an unordered sequence of more than 500 images belonging to the whole site. On the contrary, using the original images, it has not been possible to align all the cameras. Moreover, the corrected images allowed for creating a model mapped with a high-quality texture, comparable with original images in terms of resolution, and with a fair colour balance, since the whole dataset shares the same colour statistics.

Even if these techniques have been used in other works related to underwater archaeology, this experimentation represents a significant case-study to verify their robustness in presence of strong turbidity and poor visibility conditions of a submerged environment.

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