UNDERWATER NON-LINEAR CAMERA CALIBRATION: AN ACCURACY ANALYSIS

Amanda P. Silvatti[1] Thiago Telles[1] Marcel M. Rossi[3] Fábio A. S. Dias[4] Neucimar J. Leite[2] and Ricardo M. L. Barros[1]

Faculty of Physical Education[1], Institute of Computing[2], University of Campinas, Campinas, Brazil.
School of Sport Science[3], Exercise and Health, University of Western Australia, Perth, WA, Australia.
Laboratoire d'Informatique Gaspard-Monge[4], Université Paris-Est, ESIEE 2, Noisy-le-Grand Cedex, France

KEYWORDS: non-linear camera calibration, 3D underwater analysis.

INTRODUCTION: One of the most challenging problems associated with underwater 3D movement analysis is the accurate calibration of the cameras. Additional sources of errors are present in underwater acquisitions such as the nonlinear distortion caused by water interface, camera lenses (ex. wide angle) and housing's glasses. Despite this, in the literature, systems based on a linear calibration model (DLT) were proposed (Yanai et al., 1996; Machtsiras & Sanders, 2009; Gourgoulis, et al. 2008). However, the results of underwater accuracy were not similar to those obtained out of the water. In Kwon, et al. 1999, the use of a modified DLT algorithm to model the distortion was proposed but the results of accuracy were not substantially improved, with Root Mean Square (RMS) values ranging from 5.6 to 7.2mm. Recently, alternative approaches were proposed to non-linear camera calibration and submillimeter accuracy was reached (Cerveri et al., 1998; Zhang, 2000; Pribanić, Sturm & Cifrek, 2008). However, these approaches were not applied underwater. In previous work, a new non-linear calibration method using a straight line plane object was proposed and tested out of the water (Silvatti et al., 2009 available in http://calib.googlecode.com). In this work, this novel method was tested in underwater conditions and its accuracy evaluated.

METHOD: A kinematic analysis system (DVideo, Figueroa et al., 2003) was adapted for underwater online data acquisition. The system consisted of a computer connected to two Basler cameras (50Hz, wide angle lens) enclosed in housings specially designed. Tripods were adapted with suction cups to fix it on the swimming pool floor. The cameras were synchronized by a gen-locked trigger. The non-linear camera calibration method required eight points with known coordinates to define the extrinsic parameters and the acquisition of the motion of a chess board to obtain the intrinsic and distortion parameters. The waterproof plane object (chess board) contained a 5x6 squares pattern defining straight orthogonal lines (100mm x 100mm with 42 corners). The chess board was moved in the whole acquisition volume ($4.5x0.6x1m^3$) and tracked automatically in approximately 300 frames. The accuracy was evaluated in a dynamic test using a rigid bar and the follow variables were calculated: a) the mean absolute errors b) the standard deviation, c) the minimum and d) maximum error, e) the RMS of the distances between two markers (expected value=283.14mm) obtained as a function of time (15 seconds) and f) the RMS relative to reconstruction expressed as a percentage of the real length of the rigid bar's movement.

RESULTS: Table 1 shows the variable values: mean, standard deviation, minimum error, mean absolute errors, maximum error, RMS of the distance curves between markers and the %RMS for the proposed method in dynamic test.

Table 1. Results of the method proposed in the rigid bar dynamic test. Expected bar length 283.14mm. Values expressed in millimeter (mm).

	Mean	Standard Deviation	Minimum Error	Mean Absolute Error	Maximum Error	RMS	%RMS
Proposed Method	283.22	0.80	0.07	0.64	4.57	0.80	0.28

DISCUSSION: The mean absolute error presented in Yanai et al. (1996) was 5.12mm compared to 0.64mm in the proposed method. The %RMS found in Gourgoulis et al. (2008) was 1.28%, in a 4.5x2x1 m^3 acquisition volume, and 0.65% in a 1x1x1 m^3 acquisition volume. The proposed method reached a better value in both cases (0.28%) with an acquisition volume of 4.5x0.6x1m^3. Using the regular DLT method, Kwon et al. (2000) obtained RMS and maximum error values of 39.3mm and 17.4mm, respectively. Applying a new modified DLT algorithm including distortion correction parameters and the RMS value ranged from 5.6mm to 7.2mm and maximum error ranged from 9.3mm to 9.7mm, compared to the 0.8mm and 4.57mm in the proposed method. The results of the proposed method can be compared to high accurate calibration method in out of the water condition. According to Pribanić et al., (2008) the accuracy found in two non-linear camera calibration methods (wand calibration and 2D plane model) were smaller than 1mm. Another advantage in the proposed method is the simplicity and the portability of the system due to the requirement in terms of calibration objects. The proposed method required only a waterproof planar chess pattern, previously assembled, and few markers with known coordinates. Most calibration methods used in Biomechanics require the construction and transportation of rigid volumetric structures with many markers. This kind of object is very difficult to measure when large volumes are involved.

CONCLUSION: The results of the proposed method provided better underwater accuracy compared to all previous papers reported in the literature. The results of the underwater chess method revealed to be an applicable alternative with good accuracy and portability for underwater non-linear camera calibration.

REFERENCES:

Cerveri, P., Borghese, N.A., & Pedotti, A. (1998). Complete calibration of a stereo photogrammetric system through control points of unknown coordinates. *Journal of Biomechanics*, 31, 10, 935-940

Figueroa, *et al*. A flexible software for tracking of markers used in human motion analysis. *Computer Methods and Programs in Biology, v. 72*, n. 2, p. 155-165, 2003.

Gourgoulis, *et al.* (2008) Reconstruction accuracy in underwater three-dimensional kinematic analysis. *Journal of Science and Medicine in Sport*, v.11, p.90-95.

Machtsiras,G. & Sanders R. H. (2009) Accuracy of portable (PTZ digital) camera system designed for aquatic three-dimensional analysis, *27th International Conference on Biomechanics in Sport*, Limerick, Ireland, p.451.

Kwon, Y.-H., & Lindley, S.L. (2000). Applicability of the localized-calibration methods in underwater motion analysis. *16th International Conference on Biomechanics in Sports,* Hong Kong, China.

Pribanić, T., Sturm, P., & Cifrek, M. (2008). Calibration of 3D kinematic systems using 2D calibration plate, *26th International Conference on Biomechanics in Sport, Seoul,* Korea, 77-80.

Silvatti, A.P., et al. (2009) Non-linear camera calibration for 3D reconstruction using straight line plane object, *27th International Conference on Biomechanics in Sport*, Limerick, Ireland, p.644.

Yanai, T., Hay, J. G. Gerot, J. T. (1996) Three-dimensional videography of swimming with panning periscopes. J. Biomechanics, v. 29, n. 5, p.673-678.

Zhang, Z. (2000) A flexible new technique for camera calibration, *IEEE Transactions on Pattern Analysis and Machine Intelligence,* 22, 11, 1330-1334.

Acknowledgement

Research supported by FAPESP (00/01293-1, 06/02403-1, 09/09359-6), CNPq (451878/2005-1; 309245/2006-0; 473729/2008-3) and FAEPEX (0179/2009).