THE INFLUENCE OF TWO VARIABLES OF THE NONLINEAR CAMERA CALIBRATION ON THE 3D UNDERWATER ACCURACY

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The purpose of this study was to control two variables of the nonlinear camera calibration to evaluate if they affect the 3D undewater accuracy. Two cameras (GoPro, 60 Hz) were fixed in the swimming pool. In order to evaluate the influence of a distance constrain (1 and 2 markers) and the movement of the wand calibration, we performed three different movements: M1 (zig zag), M2 (circular) and M3 (up and down). In each condition the 3D accuracy were assessed in seven trials of a dynamic rigid bar test (ANOVA, $p<0.05$). The best accuracy results were found in the M1. In this movement the wand spread more the acquisition volume. No significant difference was found when we compare this movement using or not the distance constrain, however if the movement did not spread very well the volume the usages of the distance constrain improved significantly the results.

KEY WORDS: accuracy analysis, nonlinear camera calibration, 3D underwater analysis.

INTRODUCTION: In an attempt to solve the problems of high cost of 3D motion analysis systems, some commercial cameras have been tested (Silvatti et al. 2012; Silvatti et al. 2013; Chong e al. 2011). These commercial cameras have two main features that allows their usage for biomechanics analysis: high resolution images and high speed records. The action sports cameras are an example, and their advantages are low cost, compared to optoelectronics cameras specially designed for 3D motion analysis, small size and portability. Acceptable accuracy results for underwater analysis, with this kind of camera, were found in previous work (Bernardina et al. 2014). Since the camera calibration is strictly related to the results of the 3D accuracy it is necessary to investigate the variables that can influence negatively or positively this step in order to improve the reability of the 3D data obtained with the action sports cameras. So, the purpose of this study was to control two variables (different wand movements and a distance constrain in the wand) of the nonlinear camera calibration to evaluate if they affect the 3D undewater accuracy.

METHODS: The data acquisition was performed in a vinyl swimming pool. The volume acquisition was defined by $4x1x1.5m^3$. Two action sports cameras (GoPro, Hero 3, black edition) with 2 m distance between them were fixed with suction cups on the wall of the swimming pool. We used the GoPro app (cell phone Galasy S4 active) to set the camera position, view and configuration: 1920x1080 (image resolution), 127^o (view angle) and 60Hz (acquisition frequency). A wifi remote was used to start all the cameras. The images were converted to AVI in the GoPro studio software. The Dvideo software (Figueroa et al. 2003) was used to track the markers.

An orthogonal waterproof triad (1x1x1m) with nine spherical black markers (35mm) was used to determine initial extrinsic and intrinsic parameters using DLT equations and defines the axes X, transversal, Y longitudinal and Z vertical directions (Silvatti et al. 2012). In order to calculate the nonlinear camera calibration (Cerveri et al. 1998) a rigid bar was moved in the volume (4x1x1.5m3) during 20 seconds. In order to evaluate the influence of the wand movement on the 3D underwater accuracy we performed three different wand movements: M1 (zig zag), M2 (circular) and M3 (up and down). We also evaluate the influence of a distance constrain in the wand on the 3D accuracy using the rigid bar with one or two markers. Thus, we obtained five situations of calibration: M1-1 (one marker), M1-2 (two markers), M2-1 (one marker), M2-2 (two markers), M3-1 (one marker). 400 useful frames were opportunely extracted from the whole sequence to refine the initial parameters into a bundle adjustment nonlinear optimization. The distortion was taken into account in the camera model adopting a radial model with 1 parameter.

The accuracy values were assessed in seven trials of a dynamic rigid bar test in all conditions (M1, M2 and M3). The rigid bar (two markers) was moved within the working volume during about 20s. The real size of the rigid bar was determined by computer numerical control machine (CNC) with an accuracy of about 10µm (nominal value D: 250.00mm). The distance between the markers was obtained as a function of time. The following variables were calculated: a) minimum, mean and maximum value of the distance between the markers, b) the standard deviation and c) the mean absolute error.

As data assumed normality assumptions, we applied the analysis of variance (ANOVA, $p<0,05$) to determine if the wand movements and a distance constrain in the wand affected the accuracy results. We used the *post hoc* Tukey ($p<0,05$) to find the statistical significance between the five situations (Matlab® 2012).

RESULTS AND DISCUSSION: Table 1 shows the variables calculated.

Table 1: Minimum, mean and maximum results of the 7 trials of dynamic rigid bar test for each situations of calibration and results of post hoc Tukey.
D: 250mm. Values expressed in millimeter (mm).

Calibration	Distance			Mean Absolute Error	Comparison	P
	Minimum	Mean	Maximum			
M1-1	249,31	249.46	249,60	1.21	M1-2	0.389
					M2-1	0.000*
					M2-2	0.000*
					M3-1	0.000*
M1-2	249,07	249.19	249,38	1.32	M2-1	0.000*
					M2-2	0.046*
					M3-1	0.000*
M2-1	248,54	248.63	248,92	1.83	M2-2	0.000*
					M3-1	0.000*
M2-2	248,90	248.99	249,17	1.51	M3-1	0.000*
M3-1	247,92	248.20	248,72	2.65		

***$p<0.05$; M1-1 (Movement 1 – 1 marker); M1-2 (Movement 1 – 2 markers); M2-1 (Movement 2 – 1 marker); M2-2 (Movement 2 – 2 markers); M3-1 (Movement 3 – 1 marker)**

There is a significal effect between the five situations of calibration, F(4,30) = 168,294, $p<0,001$, ω=0,97. Since the M1 spread more the acquisition volume we found the best accuracy results in the M1-1 (1.21mm). No significant difference was found when we compare the same movement using or not the distance constrain (Table1). When the movement did not spread very well the volume the usages of the distance constrain improved significantly the accuracy results (M2-2 = 1.51mm; M2-1 = 1.83mm, $p<0.001$) (Table1).

Previous works, that evaluated the accuracy out of the water, found values that ranged from 0.58mm to 0.75mm (Pribanic et al., 2008; Silvatti et al. 2013). However, on the market, there are commercials systems for 3D underwater analysis that report a relative accuracy of 2mm at 10 meters distance (Oqus – Underwater, Qualysis, Sweden). In this work, in all trials, using two cameras, the mean absolute error ranged from 1.09mm to 2.91mm in 4 meters. Our best accuracy result (1.09mm M1-1 to 1.45mm M1-2) are comparable with the values reported by others works that used the wand calibration (Silvatti et al. 2012; Bernardina et al. 2014).

It is important to highlight the mainly benefit to use this kind of camera. In this work, we presented an alternative to obtain accurate 3D data with low cost and flexibility. Thus, we could assert that 3D analysis of several underwater movements are potentials applications, as swimming, gait, water aerobics, Hydrospinning, water polo and etc.

For future studies is necessary to research variables and situations that can affect the nonlinear camera calibration. Possible questions to investigate could be the 1. reproducibility to use the action cameras, 2. more cameras, 3. evaluate and compare their usage to out water and underwater applications, 4. test others frequencies and 5. feasibility in differents water sports.

CONCLUSION: We can assert that the movement of the wand calibration influences the accuracy results and the best accuracy results were found in the M1. In this movement the wand spread more the acquisition volume. Furthermore, the results showed that the distance constrain is not more important than to spread the volume very well. However, if the movement did not spread very well the volume the usages of the distance constrain improved significantly the results.

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