ACCURACY OF SPORT ACTION CAMERAS FOR 3D UNDERWATER MOTION ANALYSIS

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The purpose of this study was to evaluate the accuracy of sport action cameras for 3D underwater motion analysis. Two cameras (GoPro) were fixed in the swimming pool. The image resolution was set to 1920 x 1080, the view angle was set to 127º and the frame rate was 60 Hz. A Wi-Fi remote was used to start the cameras. A wand calibration method based on radial distortion model was used to calibrate the cameras. The accuracy was evaluated in eight trials of dynamic rigid bar tests (working volume $4\times1\times1.5m^3$). The results revealed mean absolute error ranging from 1.23 mm to 1.93 mm. These values of accuracy for underwater analysis can be considered acceptable for the majority of 3D underwater motion analyses, in particular for swimming biomechanics.

KEY WORDS: accuracy analysis, non-linear camera calibration, 3D underwater analysis.

INTRODUCTION: In the literature it is normal to find works using a linear calibration model (DLT) for 3D underwater analysis (Yanai et al., 1996; Machtsiras & Sanders, 2009; Gourgoulis, et al. 2008). However, this camera model disregards the lenses optical distortions that strongly impact the accuracy of the reconstruction. Nowadays, with the proposition of nonlinear camera calibration methods (Cerveri et al. 1998 Zhang, 2000; Pribanić, Sturm & Cifrek, 2008) the accuracy results were improved and submillimeter accuracy was reached in the underwater applications using CCD cameras (Silvatti et al. 2012).
Commercial cameras incorporate some extremely useful features for biomechanics, such as high speed records and high resolution images, furthermore they were available in a very low cost. The action sport camera is one of them and was designed to be use in different sports, even for underwater sports. Different accessories and mounts were developed to fix the camera, which could increase the flexibility to acquire images for a biomechanics 3D motion analysis. This camera was already used for biomechanics analysis, (McDonnell et al. 2012), nevertheless, it was a 2D analysis and the accuracy was not reported. Thus, the purpose of this study was to evaluate the accuracy of these very low cost and flexible cameras using a nonlinear camera calibration for 3D underwater motion analysis.

METHODS: The data acquisition was performed in a vinyl swimming pool. Two sport action cameras (GoPro, Hero 3, black edition) were fixed with a specially designed suction cups in the swimming pool border. In order to set the camera configuration, position and view the GoPro app installed in a cell phone (Galasy S4 active) was used. The image resolution was set to 1920 x 1080, the view angle was set in 127º and the acquisition frequency was 60Hz. In order to start the cameras a Wi-Fi remote was used. The images were converted in the GoPro studio software to AVI. The marker tracking was performed in the Dvideo software (Figueroa et al. 2003). In order to perform the wand calibration (Cerveri et al. 1998), an orthogonal waterproof triad ($1\times1\times1$m) with nine spherical black markers (35mm) was used to determine initial extrinsic and intrinsic parameters using DLT transformation and defines the axes X, transversal, Y longitudinal and Z vertical directions (Silvatti et al. 2012). The moving wand, carrying one marker at its end, was acquired in the whole working volume ($4\times1\times1.5m^3$) during 20 seconds. 400 frames were opportunely extracted from the whole sequence to refine the initial parameters into a bundle adjustment nonlinear optimization, which uses control points with both known (triad markers) and unknown (wand marker) 3D coordinates. The bundle adjustment iteratively estimates the parameters of all the cameras along with the unknown 3D coordinates by minimizing the 2D projection error (measured vs. predicted by the camera model) on the image. The distortion was taken into account in the camera model adopting a radial model with 1 parameter. The accuracy was assessed on eight acquisition of a rigid bar (two black markers) moved within the working volume during 15s. 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) mean value of the distance, b) the standard deviation and c) the mean absolute errors.

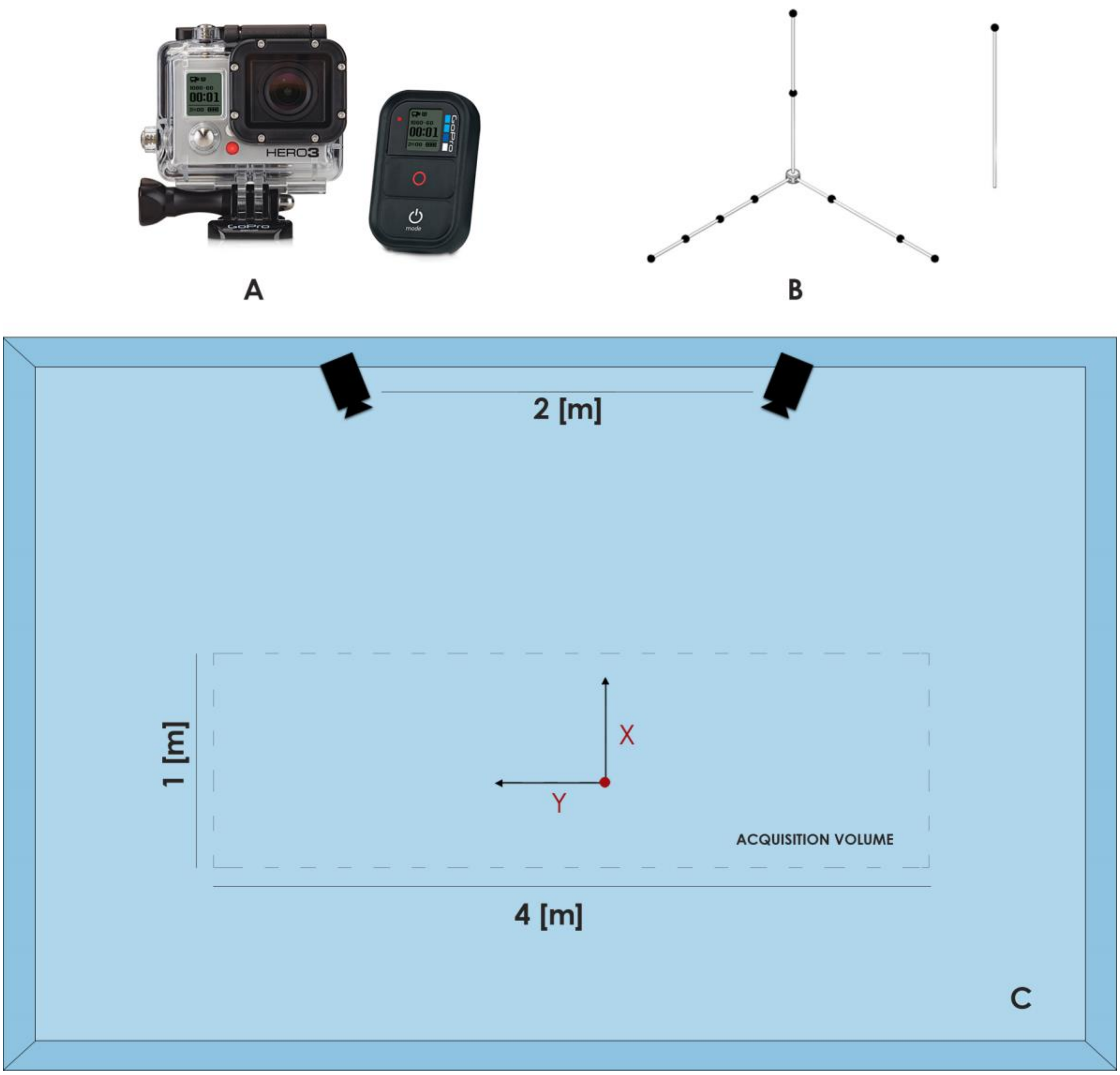

Figure 1 – A) Action sport cameras used and the Wi-Fi remote. B) Orthogonal waterproof triad and wand used for the wand calibration and C) Camera position and the working volume.

RESULTS AND DISCUSSION: Table 1 shows the mean of the distance between the markers, standard deviation, mean absolute errors of the eight trials of the dynamic rigid bar test.

Table 1: Results of the 8 trials of dynamic rigid bar test. D: 250mm. Values expressed in millimeter (mm).

Trial	Mean	Standard Deviation	Mean Absolute Error
Trial1	249.66	2.11	1.67
Trial2	249.97	1.56	1.25
Trial3	249.22	2.25	1.78
Trial4	249.28	2.69	1.93
Trial5	250.27	2.07	1.68
Trial6	250.35	1.94	1.53
Trial7	250.37	1.69	1.36
Trial8	250.10	1.52	1.23

The standard deviation ranged from 2.69mm (trial 4) to 1.52mm (Trial 8) and were worse than the values found in previous work (0.69mm, Silvatti et al. 2012).The mean absolute error raged from 1.93mm (trial 4) to 1.23mm (Trial 8). Pribanic et al., (2008) using the same calibration method, reported accuracy values ranging from 0.66mm to 0.75mm for out of the water applications. In previous work, the underwater accuracy was 1.16mm (Silvatti et al. 2012). Our results were worse than both works (Pribanic et al., 2008, Silvatti et al. 2012). However, they were better than the underwater accuracy previously reported in the literature based on a linear calibration (Yanai et al., 1996; Kwon et al., 2000 and Gourgoulis et al., 2008). Commercial system for 3D underwater analysis reported a relative accuracy of 2mm at 10 meters distance (Oqus – Underwater, Qualysis, Sweden). Using two cameras we found values ranging from 1.93mm to 1.23mm in 4 meters, therefore our accuracy results were acceptable for underwater analysis.

It is important to highlight that the camera system tested in the present study could be used for 3D underwater analysis of different motions with acceptable accuracy. Another point to be highlighted is the camera that is inexpensive and portable.

CONCLUSION: The accuracy values found out of water and underwater, which were reported in previous work, were both better than our accuracy results. However, underwater analysis based on linear calibration presented accuracy results worse than the values found in this work. These values of accuracy for underwater analysis can be considered acceptable for the majority of 3D underwater motion analyses, in particular for swimming biomechanics.

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