MARKERLESS UNDERWATER MOTION CAPTURE

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SUMMARY

Markerless motion capture techniques are only based on synchronized video sequences of the subject and allow noninvasive measurements of body segments kinematics [1]. Furthermore, it can be performed in non-controlled environments where markers cannot be employed. Since the motion in front-crawl swimming requires underwater three-dimensional (3D) motion analysis, markerless systems represent a valid solution. In the present work a video-based markerless system employing commercial subaqueous video cameras for the analysis of arm movements during front crawl swimming was developed. The data of an elite swimmer were acquired. Trajectories and velocity of wrist, elbow and joint centers were determined. The data were compared with a manual-digitization technique.

INTRODUCTION

During the last decade markerless motion capture techniques have gained an increasing interest in the biomechanics community. Furthermore, it can be performed in non-controlled environments where markers cannot be employed. An exemplary case is the kinematic analysis of swimmers, which requires underwater human motion tracking, therefore it cannot rely on retro reflective marker based motion capture systems. The major drawbacks of the state of the art of swim biomechanics are the manual digitization of feature points on video sequences of the subject, which is a time consuming task, and that it has often been limited to the sagittal plane. The aim of the present work is the development of a video-based, markerless system for the analysis of arm movements during front crawl swimming.

METHODS

One elite sprint swimmer (age 25 years, height 1.82 m, weight 91 kg) participated as subject for the experiment. A front crawl trial was acquired and analyzed with markerless and a manual-digitization technique (SIMI, SIMI Reality Motion Systems GmbH). Six underwater colour analog cameras (TS-6021PSC; Tracer Technology Co. Ltd) were employed in the experiments. Each camera was connected to a FireWire (IEEE 1394a)-equipped notebook through an Analog to Digital Video Converter (Canopus ADVC55; output DV video, PAL interlaced, 25 frames/second). A total of 4 notebooks was used; out of them, 2 were equipped with PCMCI. All notebooks were linked to a hub through Ethernet cables. The swimming pool was 25 meters long and 16 meters wide; depth varied from 1.20 to 1.70 meters, but acquisitions only regarded the deepest half. A calibration grid, sized 2.07 x 1.07 x 1.40 meters was placed at the center of the volume of interest before the actual acquisition, and used for the calibration of the extrinsic parameters of the cameras. A wooden panel with a checkerboard pattern drawn on it (13 x 9 black and white squares, side 42 millimeters) was employed for the calibration of the intrinsic parameters [2].

In order to synchronize the acquisition from all cameras, a custom-made software that was developed in C++ . Silhouette extraction was performed employing a Gaussian mixture algorithm (Intel OpenCV library), which creates an adaptive model of the background; a priori information, in terms of an extra “white” Gaussian component of the model, was included in order to deal with the presence of the foam. From the intersection of these silhouettes’ back-projections in space, a visual hull of the subject was obtained at each frame. The joints’ position was reconstructed by means of matching the visual hull with a subject-specific mesh model (obtained from a dry and static visual hull of the subject), based on rigid-segments, employing the articulated-ICP algorithm [1]. Only a manual initialization step is required, in which the initial position of the wrist is determined by digitizing its position on each view, and triangulating them. The kinematic properties of the model were specialized for the analysis of arm kinematics. The hand was chosen as root segment of the kinematic chain instead of the trunk in order to allow joint trajectory reconstruction in the initial phase of the stroke, when only the arm is in view of all cameras. 3D trajectories of wrist, elbow and joint centers were determined. 3D joints’ velocity were calculated by first-order differentiation of trajectories. No filtering was applied to the data.

RESULTS AND DISCUSSION

3D trajectories of wrist, elbow and joint centers were evaluated (see example of the wrist joint in Figure 2). RMSD values between markerless and average manual-tracking trajectories were determined (Table 1), for each coordinate.

The stroke of the subject of this study presents a *downsweep* phase (Figure 2) characterized by a downward displacement of 26 cm and a contemporary outward movement of 40 cm. In this same phase, the reaching of *catch* position can be identified as occurring at 60% of the underwater stroke period. Larger errors occur instead for elbow and shoulder joints. Systematic difference in the sagittal plane can be due to the rigid-body assumption that is introduced in the definition of the kinematic model for markerless analysis.

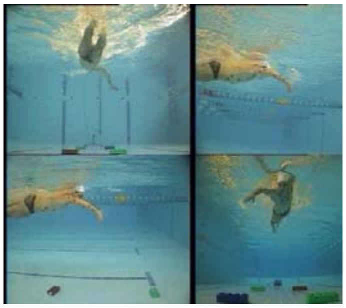

Figure 1: Example of synchronized views.

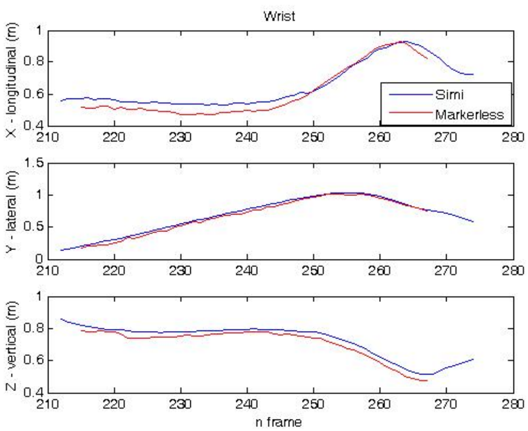

Figure 2: Coordinates of wrist joint trajectory reconstructed with SIMI (blue) and markerless (red) systems.

CONCLUSIONS

Upper arm 3D kinematics during a front crawl stroke was reconstructed by means of an automatic markerless technique that was tailored to operate properly underwater. Common out-of-shelf subaqueous cameras were employed. Main modifications regard the calibration procedure and the advanced image analysis algorithms that were employed. Joint trajectories estimation accuracy was evaluated in terms of RMSD with respect to trajectories obtained with a conventional 3D reconstruction technique, implemented in commercially available software. Accuracy at wrist joint level is deemed to be sufficient; this is most important for the technical analysis of the stroke, as hand trajectory is commonly used to identify and characterize stroke phases [3].

ACKNOWLEDGEMENTS

We acknowledge Andrea Giovanardi and Stefano Ceccon for their help in the data collection.

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Table 1: RMSD values between markerless and average manual-tracking trajectories for each coordinate.

	X	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
RMSD (mm)	**120.7**	**50.4**	**48.6**	**92.8**	**56.5**	**22.3**	**34.9**	**23**	**14.4**
	Shoulder			**Elbow**			**Wrist**		