BRG.LifeMOD™ modeling and simulation of swimmers impulse during a grab start

Guillaume Agnesina[1], Redha Taiar[1], Nicolas Houel[2], Kevin Guelton[3], Philippe Hellard[2], Yuli Toshev[1, 4]
[1] Laboratory for Analysis of Mechanical Constraints LRC/CEA EA 3304, University of Reims CA, France
[2] FFN, INSEP, Paris, France
[3]CRESTIC, University of Reims CA, France
[4]Institute of Mechanics and Biomechanics, Bulgarian Academy of Sciences, Sofia, Bulgaria

***Abstract*—-The main aim of the study is to propose an approach for 3D modeling and simulation of swimmers impulse during a grab start. Four national level swimmers were investigated. For every swimmer, 3D model was generated in BRG.LifeMOD™ on the base of individual morphologic parameters and kinematic data obtained by high speed video camera and passive markers attached at the level of each important articulation. The proposed approach allows predicting swimmer's joint moments for each important articulation during the impulse phase of the grab start and to analyze the segmental coordination for each studied swimmer in order to optimize the performance. The model was successfully validated by comparing the predicted speed and power values with experimental ground reactions data collected in situ.**

Keywords—3D modeling; swimming; grab start; kinematics; joint moments

I. Introduction

Whatever the swimming disciplines, the study of swimmers' performance involves the identification of three technical phases: start, turn and strokes phases. The analysis of the temporal distribution has shown that the start phase accounts for 15 % and 7.7 % of total time, respectively for 50 m and 100 m freestyle events. In short distance races (50m and 100m), the start represents a particularly important factor. For instance, at Athens Olympic Games (2004), the time that separated the eight men's 50m freestyle finalists was 0.44 s, this represents 2% of the winner's total race time (21.93 s). Performance differences between the finalists may find an explanation in accordance to the time lost during the start phase.

In spite of underwater factors, the start phase depends primarily on the quality of the swimmer's impulse on the starting platform (Vilas-Boas et al., 2003). Although recent studies using both dynamics and kinematics approaches, they do not provide additional information concerning the relationship between the swimmers' movements and their actual performance. Few studies focused on the modeling (dynamic and/or kinematics) of the parameters in order to determine the performance according to swimmers' movement during start phases (Holtes and McLean, 2001). Note that modeling methods used for movements study in others sports, for instance skiing (Houel, 2004), seem to be the most effective for a detailed understanding of movements and for performance prediction.

The aim of this study is to develop an approach for 3D modeling and simulation of swimmers impulse during a grab start in order to optimize the performance.

II. Methods

One national level swimmer was asked to perform a grab start. Subject's height and mass were respectively 179 cm (± 1) and 72,2 kg (± 0.2). Swimmers were fitted out with 16 passive markers (8 on the right and 8 on the left side) fixed on anatomical point relating to each important articulation: foot, ankle, knee, hip, shoulder, elbow, wrist, finger (Fig.1).

For each start, 3 high speed video cameras (Photron Fastcam PCI at 125 Hz) were used. The most important data were obtained by the two cameras in the two sagittal views (right and left). Simultaneously, the ground reaction force was measured using a 3D force-plate AMTI OR6-7-2000 mounted on the start block (Fig. 1) with sampling frequency of 1000 Hz.

Swimmer's segment center of mass velocities were computed from acceleration values integration. Before each start, video cameras and force-plate were calibrated and clock synchronized (0.008 s accuracy).

A particular attention has been made to the numerical derivative process and to the filtering process. 90% of the spectral power density of the center of mass excursion is situated between 0 and 6 Hz (Carpenter et al., 2001). Thus, to reduce noise, both video and force-plate (needed in the following results) data were filtered through a fourth-order zero-phase lag filter with a cutoff frequency of 6 Hz (Gustafsson, 1996, Mitra, 2001).

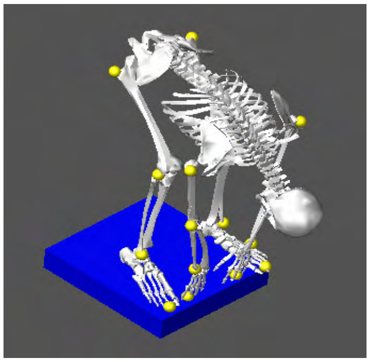

Figure 1. Passive markers positions (8 on the right and 8 on the left side). AMTI force-plate mounted on a block.

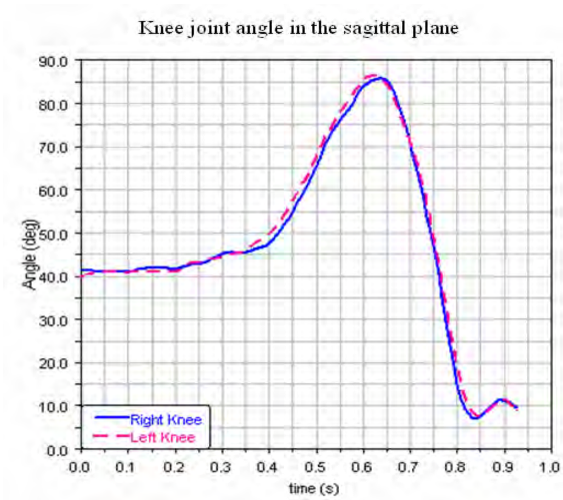

Figure 2. The swimmer's knee joint angles (right and left) obtained using high sped video cameras and passive markers.
Time period: 0.00s to 0.92s

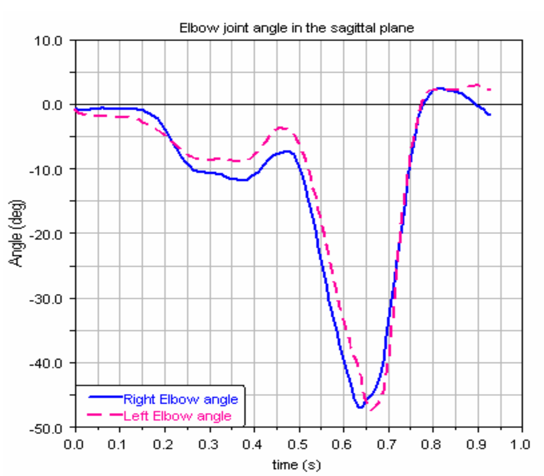

Figure 3. The swimmer's elbow joint angles (right and left) obtained using high sped video cameras and passive markers.
Time period: 0.00s to 0.92s

Two-dimensional video analysis was carried out for the impulse phase, i.e. during the period when the athletes were in contact with the force-plate mounted on the start block. The video analysis allowed determining the angles between the subject's segments axes and the horizontal plane. The data were fitted using polynomials' method (Tavernier et al, 1996; Winter et al, 1990).

The swimmer's knee and elbow joint angles (right and left knee elbow) were obtained using high sped video cameras and passive markers. These are shown on Fig. 2 and Fig. 3. Afterward they were used as input data for the 3D modeling.

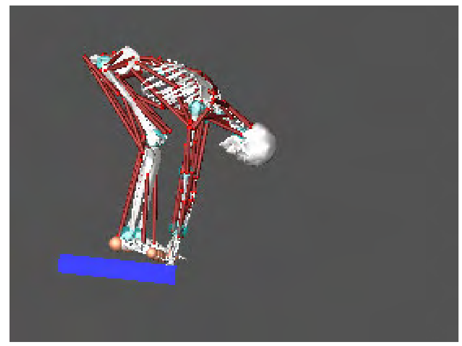

Figure 4. 3D suimmer's body model in the initial moment of the impulse phase. Time = 0 s

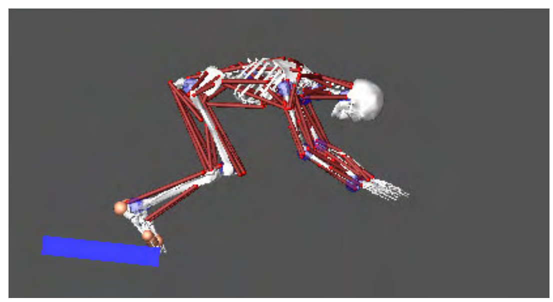

Figure 5. 3D suimmer's body model in the maximal efforts moment of the impulse phase. Time = 0.6013 s.

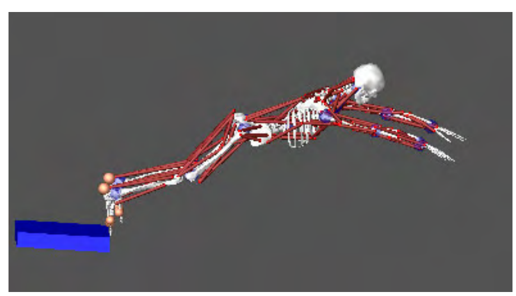

Figure 6. 3D suimmer's body model in the final grab start moment. Time = 0.784 s.

The subject's inertial parameters were defined using the measured values for the height and the mass and the anthropometric tables from Dempster et al., 1959. The obtained joint torques are computed from the Newton-Euler equation as defined in Winter (1990).

During the impulse phase, subjects were represented using an open tree structure composed of eight straight segments connected via frictionless joints (Fig. 1). The model input data consisted on the fitting angles computed at each joint (Fig.2 and Fig.3) as well as the subject's inertial parameters.

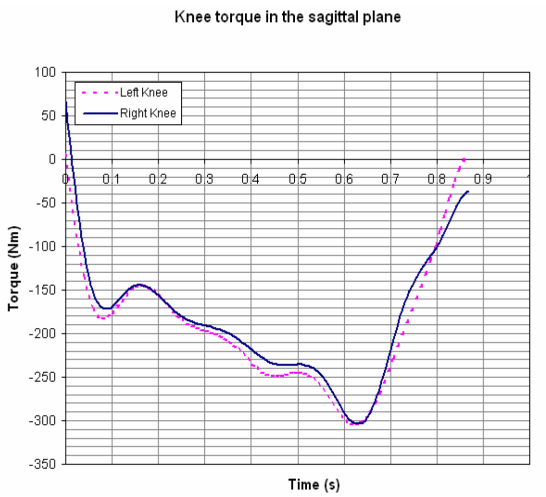

Figure 7. The knee joint torques (right and left). Time period : 0.00 s to 0.92 s.

Based on the analysis of swimmer's forces and joint torques during the impulse, the goal of the model is to better understand the grab start movement by studying joins mechanical characteristics.

III. RESULTS

For this swimmer, a 3D model was generated using BRG.LifeMOD^{TM} Biomechanics Modeler on the base of individual inertial parameters and kinematics data. These are obtained from high speed video measurement using passive markers fitted out on each important articulation. 3D swimmer's body models for four characteristic torques during the grab start are shown: for the initial torques of the impulse phase, t = 0 s (Fig. 4); for the maximal efforts torques, t = 0.6013 s (Fig. 5); for the final start torques, t = 0.8781 s (Fig. 6).

For each joint, the dynamic torques and force were computed based on the inverse dynamics method, i.e. using the Newton Euler equations (Winter, 1990; Houel, 2004). The time history of right and left knee joint torques from t = 0.00 s to 0.92 s are shown Fig. 7. The velocities of the segments centers of mass were also computed. The time history of the pelvis center of mass in the sagittal plane from t = 0.00 s to 0.92 s are shown on Fig. 8 (along the x-axis (horizontal) and the y-axis (vertical)). The model was validated comparing the predicted ground reaction force with the AMTI force-plate one during the grab start period. The time delay between the simulation results and the measured ones can be explained by the fact that the swimmer takes support on the edge of the force plate in experimental conditions. (Fig. 9).

IV. CONCLUSION

The proposed approach allows predicting swimmer's joint torques during the impulse phase of the grab start. The model was validated comparing the predicted ground force with the measured one during the grab start period. In further works, the interest of such studies should be the segmental coordination analysis by means of relative phases (Delpierre et al., 2005, Li et al., 1999) associated with muscular activation investigation for each swimmer in order to optimize their performances.

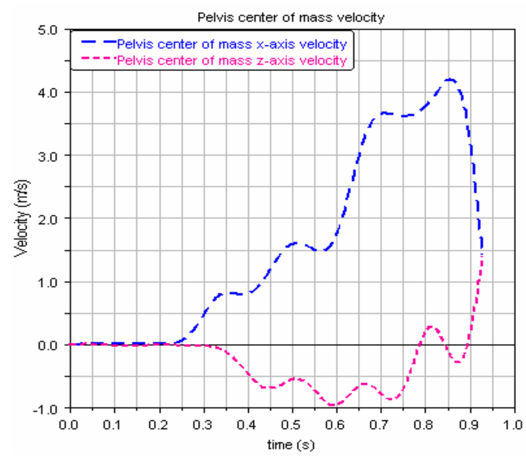

Figure 8. The velocity/time functions of the pelvis centre of mass in the sagittal plane for the time period 0.00 s to 0.92 s

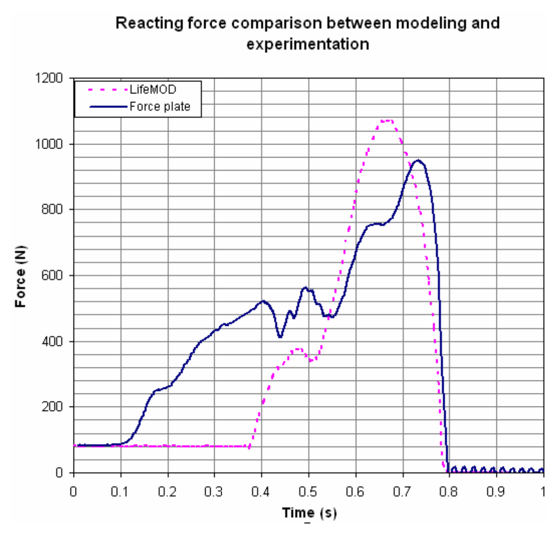

Figure 9. Comparison between the mesured ground reaction forces (bold) and the predicted by the model during the start period of maximal efforts

REFERENCES

[1] Dempster W.T.,. Felts W.C. and W.J.L, "The anthropometry manual work space for the seated subjects", American J. of Physiology and Anthropometry, vol. 17, 1959, pp. 289-317.

[2] Holthe M.J. and McLean S.P., "Kinematic comparison of grab and track starts in swimming", Biomechanics Symposia, Munich, 2001, pp. 31-34.

[3] Houel N., "Interests and limits of the kinematic analysis by imagery. Contribution to the realization of models kinematics and dynamic of the movement. Application to nordic skiing and ski jumping.", PhD thesis, University of Poitiers, France, 2004.

[4] Vilas-Boas J.P. and Fernandes R., "Swimming starts and turns: Determining factors of swimming performance", 3ème Journées spécialisées de Natation, Lille, France, 19-20 June, 2003.

[5] Tavernier M., Cosserat P. and Ruby A., "Optimisation de l'ajustement de trajectoires par lissage avec des polynômes d'ordres multiples élevés: comparaison avec le filtre de Butterworth du second ordre", Science et Motricité, vol. 28, 1996, pp. 53-56.

[6] Winter D.A., "Biomechanics and motor control of human movement.", Second Edition, Wiley Interscience Publication, 1990.

[7] Carpenter M.G., Frank J.S., Winter D.A., Peysar G.W., "Sampling duration effects on centre of pressure summary measures"., Gait & Posture, Vol 13, n°1, pp35-40, 2001.

[8] Gustafsson F., "Determining the initial states in forward-backward filtering", IEEE Transactions on Signal Processing, Vol 44, pp988-992, 1996

[9] Mitra S.K., "Digital Signal Processing", 2nd ed., McGraw-Hill Ed. 2001

[10] Delpierre Y,. Filipetti P., Kolanowski E., Guelton K., "The knee kinematical coordination investigation of IMC child during gait", The 3rd European Medical and Biological Engineering Conference, Prague, Czech Republic, 20-25 November, 2005

[11] Li L., Van den Bogert E.C.H., Caldwell G.E., Van Emmerik, R.E.A, Hamill J., "Coordination patterns of waling and running at similar speed and stride frequency", Human Movement Science 18 pp. 67-85, 1999