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Using motion-based estimated action of the diver to characterize diving board dynamics: a pilot study

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1. Introduction

Accurate models of the diver and the diving board are required to better understand the interaction between these two entities during a springboard dive.

Cheng et al. (2005) modelled the diving board as a rigid bar with torsional stiffness at origin. A 4-segment diver model was linked to the diving board free edge by frictionless revolute joint. Yeadon et al. (2006) modelled the diving board as a uniform rod with 3 DOF. An 8-segment diver model was linked to the diving board free edge using spring-damper systems.

In this study, a weak coupling between a finite element diving board model and an 18-segment diver model is proposed. The interaction forces and moments (IF&M) between the diver and the diving board are predicted using a human-motion-based forces prediction method. The predicted IF&M are applied on the diving board model. The diving board model parameters are optimized in order to minimize discrepancies between experimental and numerical vertical displacements.

2. Methods

2.1 Motion capture data

Motion capture data were recorded using an optoelectronic system (200 Hz, Qualisys). A set of 50 reflective markers were placed on diving board sides (49 on a side and 1 on the other side) and 45 on a single subject (1.65 m, 66.7 kg) following ISB standards.

During the single trial studied, the subject performed leg-induced oscillations at the diving board free edge.

2.2 IF&M prediction method

This method has been implemented in the CusToM Matlab toolbox (Muller et al. 2019).

The diving board was regarded as a succession of rigid and rectangular surfaces. Contact under the subject's feet was considered possible only on a set of 28 discrete contact points, named prediction points (PP).

The following method was followed for each frame. Firstly, for each PP, the closest diving board marker according to the x-axis (Figure 1) was detected. The set of diving board markers selected formed the potential contact surface (PCS). Secondly, a PCS frame was created using the 3D displacements of the PCS markers and the single marker on the other side. Thirdly, relative position and velocity criteria were checked to know if the contact was active or not between each PP and the PCS. The external forces applied on each active PP were minimized with respect to the dynamic equilibrium of the subject (Muller et al. 2020).

2.3 Diving board modelling

The diving board model has been implemented in the ATL4S Matlab toolbox (Grange 2021). The diving board was modelled as a bi-supported planar homogeneous Bernoulli beam (Figure1).

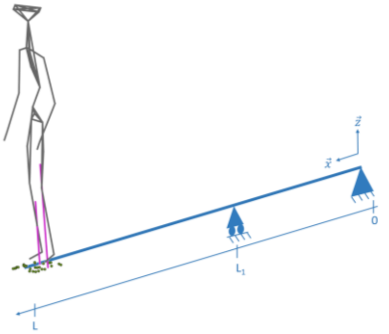

Figure 1 Diver (IF&M for each foot in purple and PP in green) and diving board models

The IF&M from left and right feet were summed and applied on the node closest to the middle of the PCS.

The contact between the diving board and the unilateral support at $x = L_1$ was managed using complementarity method (Acary 2013). The Euler theta method was used for time integration. L_1, L and the number of divisions along the x-axis were obtained from experimental marker positions. The gravity effect was taken into account. The study was started when a vertical velocity of less than 0.01 m.s^{-1} at the diving board free edge was observed.

The parameters to be determined were the Young's Modulus E (Pa), the density ρ (kg.m^{-3}), the thickness h (m) and the coefficient of restitution e.

2.4 Diving board dynamics characterization method

The characterization method aimed at finding diving board model parameters (E, ρ, h, e) allowing fitting the diving board vertical experimental displacement.

The observation time was set to 3s to catch a few oscillations periods. The parameters obtained were then used to run the ATL4S model for the complete experimental time (10.71 s).

The markers before $x = L_1$ were not taken into account because their displacements were in the region of optoelectronic system accuracy.

The following objective function was minimized using a simulated annealing method:

$$\Phi(E,\rho,h,e) = \sum_{m=S+1}^{n_m} \frac{1}{n_e|A(x_m)|} \sum_{k=1}^{n_e} (U_{exp}(x_m,t_k) - U_{num}(x_m,t_k))^2$$

$$\text{s. t.} \begin{cases} 1^{e8}\ Pa < E < 1^{e12}\ Pa \\ 10\ kg.m^{-3} < \rho < 1^{e6} kg.m^{-3} \\ 0.01\ m < h < 0.1\ m \\ 0 < e < 1 \end{cases}$$

where n_m was the number of markers used, S the number of the marker at n_e the number of time increments, A the maximum deflection at abscissae x_m, U_{exp} and U_{num} experimental and numerical vertical displacement evolution according to time (t_k) and space (x_m) respectively.

E and h are not independant parameters. A significant parameter which can be observed to give information about diving board stiffness is $\frac{EI}{b}$. b is the diving board width, which is set to 0.5 m and $I = \frac{bh^3}{12}$ is the moment of inertia.

2.5 Quantification of results

The Sprague and Geers validation metric (Schwer 2007) is used in this study to separate magnitude (M) and phase (P) errors. This metric is also based on a comprehension error factor C, which depends on M and P. Evolution of numerical and experimental vertical displacements as a function of time for each node after the unilateral support were compared. Therefore, a value of M, P and C was obtained for each node taken into account. Then, means of all absolute values of M, P and C were computed to quantify error for the whole diving board.

3. Results and discussion

The diving board model parameters were obtained after a calculation time of 25 min (Table 1).

EI/b (Pa.m^3)	ρ (kg.m^{-3})	e
1.5e5	26.7	0.15

Table 1 Optimized diving board model parameters

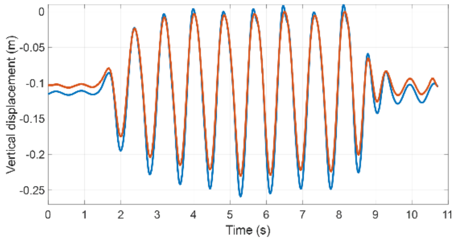

Figure 2 Experimental (blue) and numerical (red) vertical displacements at the diving board free edge

Experimental and numerical vertical displacements at the free edge were compared (Figure 2). The maximal discrepancy between experimental and numerical displacements is observed after 5.3 s, when the diving board reaches its maximum deflection. This discrepancy is 2.9 cm, which is 11% of the maximal experimental deflection. The mean values of M, P and C are respectively 4.8%, 1.3% and 5.0%.

One can conclude that the method enables to obtain a model behaviour close to the experimental one.

The diving board model is going to be improved to take into account space-variable IF&M. The application point of the IF&M should take into account the centre of pressure position under the subject's feet. The characterization method is also going to be improved to take into account several trials at the same time.

4. Conclusions

The characterization method described is a new tool to obtain a suitable model of a diving board studied experimentally. This method is appropriate for coupled structure dynamics study of the diving board and biomechanical analysis of the diver.

In the future, such a model may be a primary importance to evaluate in depth time synchronization between the diver and the diving board.

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