3D MOTION ANALYSIS OF SPEED CLIMBING PERFORMANCE

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Abstract

Speed climbing involves an optimization of the ascentional velocity during performance. Consequently, any amount of energy spent in the two other directions than vertical, namely the lateral direction and the direction perpendicular to the wall plane, is a potential loss of performance. To assess this principle, we present a study on 3D motion analysis of the center of mass (COM) of a subject during a speed climbing performance. The fundamentals of geometrical measurement in 3D require to integrate multiple 2D cues, at least two, in order to extract 3D information. We used here synchronized videos of two drones following the climber during the performance. Results show that a 3D velocity profile can be provided, pointing critical phases in the ascent where the vertical speed is not dominant any more. In this first study, the COM is approximated as a marker closed to the hips, attached to the harness. We further investigate this hypothesis with a full 3D avatar model of the climber body, acquired in the laboratory with 64 video cameras. We show that the hips marker attached on the harness has a mean distance of 12.5cm +/- 2.4cm to the true COM of the subject's body.

Keywords: Speed climbing; 3D kinematics; motion capture; center of mass; 3D avatar; Performance optimization

Résumé

L'escalade de vitesse implique une optimisation de la vitesse d'ascension pendant la performance. Par conséquent, toute énergie dépensée dans les deux autres directions que la verticale, direction latérale et direction perpendiculaire au plan de paroi, est une perte de performance potentielle. Pour évaluer ce principe, nous présentons une étude sur l'analyse de mouvement 3D du centre de masse (CDM) d'un sujet lors d'une performance d'escalade de vitesse. La mesure géométrique en 3D nécessite d'intégrer plusieurs indices 2D, au moins deux, afin d'extraire des informations 3D. Nous avons utilisé ici des vidéos synchronisées de deux drones qui suivent le grimpeur lors de la performance. Les résultats montrent qu'un profil de vitesse 3D peut être fourni, en pointant des phases critiques dans la montée où la vitesse verticale n'est plus dominante. Dans cette première étude, le CDM est approximé comme un marqueur proche des hanches, attaché au harnais. Nous étudions cette hypothèse avec un modèle d'avatar 3D complet du corps du grimpeur, acquis en laboratoire avec 64 caméras vidéo. Nous montrons que le marqueur de hanches fixé sur le harnais à une distance moyenne de 12,5 cm +/- 2,4 cm par rapport au vrai CDM du corps du sujet.

Mots-clefs: Escalade de vitesse; cinématique 3D; capture de mouvement; centre de masse; avatar 3D; optimisation de la performance.

Methods

One female climber (Anouck Jaubert, France, 2017 IFSC Speed Season Champion, mass = 55 kg, height = 1.67m) performed 8 maximal speed ascents on the official route. Mean ascent time was 8.43 ± 1.03 s. We selected the best trial (ascent time = 7.96 s) for this analysis. The performance has been filmed with two drones (DJI Mavic pro) with resolution 3840x2160 pixels at 30fps. The two drones have been temporally synchronized at the frame level with a common light signal triggered at the beginning of the performance. Center of mass of the subject has been approximated by a marker attached to her harness, close to the middle of the pelvic ilium bones. The 2D trajectory of this marker has been digitized on each video using image normalized correlation. In order to extract 3D information out of such 2D cues, it is necessary to calibrate the drone cameras into a common 3D reference frame. Calibration means that the projection from 3D to 2D is mathematically known. Compared to traditional optical motion capture system, the cameras here are constantly moving. To compute calibration in our case, we benefit from the standardization of the speed climb wall for which the metric coordinates of the holds are known. We also account for the 5 degrees inclination of the wall so that the vertical axis of the reference frame corresponds to the gravity axis. The 3D reference frame is thus made of the horizontal ground (plane XZ) and the gravity vertical axis (axe Y), with the origin at the bottom of the wall (Figure 1). Finally, similarly to the hips marker, the 2D location of the holds on the video have been digitized using image normalized correlation. These correspondence between 3D location of the holds and their 2D projection on the images allows to compute the exact calibration of the cameras. As the drones are moving with respect to the wall and we want to keep a fixed reference frame, the calibration of each camera has been computed for each frame of the videos. From the drones' cameras calibration and the 2D locations of the hips marker, the 3D trajectory of the marker can be computed using a standard DLT (Direct Linear Transform) reconstruction.

Figure 1 - The official speed climbing wall - 3D reference frame calibrated and the hip marker on the harness.

Results and discussion

We report on figure 2 the three components of the 3D position of the marker (first row). Data have been processed with a low-pass Butterworth filter (order 4, cut-off frequency 5Hz). X direction is lateral, Y direction is vertical and Z direction is perpendicular to the wall (upto the 5 degrees inclination, the YZ plane corresponds exactly to the ground). The Z component is slightly increasing as the wall moves away from the vertical axis along its height. We also report the corresponding velocity component for this marker in m/s (second row). For each of this plot, we also report the norm of the velocity (black curve). Finally, the bottom row shows the ratio of each velocity component with the velocity norm, it allows to account for the part of each velocity component to the total velocity.

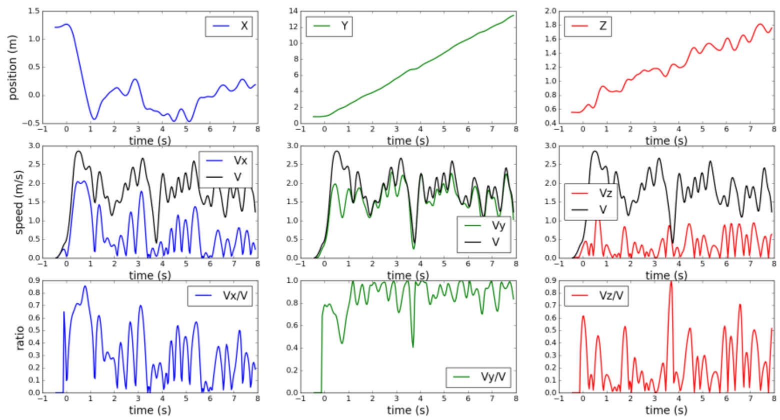

Figure 2 - Hips marker position and velocity

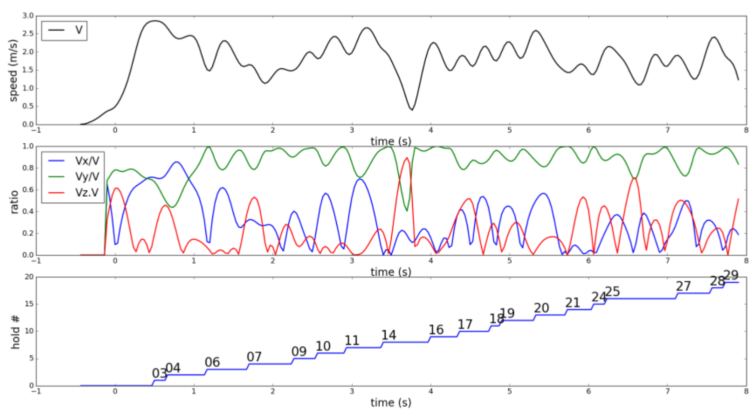

Figure 3 - Velocity components ratios profiles

On figure 3, we explore further the ratio of the velocity components with respect to the total velocity. First row is a recall of the total velocity, second row the three velocity component ratios together, and the last row indicates the evolution of the ascent with respect to “hand’ holds number (we omit “feet” holds for clarity). The curve corresponds to the steps when the hips marker y-position goes above the holds. The different plateaus thus provide an estimate of the time spent between two holds during vertical ascent.

The velocity ratio clearly outline moments when the vertical ascent is less dominant. It corresponds to "dyno" transition from hold 14 to 16 and hold 25 to 27. During these periods, the wall-orthogonal Z-axis component becomes dominant, corresponding to a posture which is getting farther from the wall. On hold 11 to 14 and hold 20 to 21, the velocity components ratios profiles show that the lateral X-axis becomes important with respect to the vertical Y-axis. They correspond to a required change of route but also show a drop in the vertical component.

As mentioned, we further examined the approximation of considering the center of mass (COM) as a fixed marker on the harness near the hips. To this end, we recorded the climber in a laboratory set-up with 64 video cameras. This experimental facility allows computing the exact 3D shape of the body in motion at 30fps. However, it is reduced to an area of view of 5m x 5m x 3m, which does not allow the usage of a real climbing wall. We thus investigated the 3D trajectory of the COM with the same climber on flat ground performing a rehearsal of the climbing performance. The COM was automatically computed from the 3D mesh as the barycenter of the enclosed 3D volume with the hypothesis of uniform density. We compared this trajectory to the trajectory of hips marker with a location closed to the one used on the harness during climbing. Results show that the mean distance between the hips marker and the true COM is 12,5 cm +/- 2,4 cm. Figure 4 illustrates the 3D reconstruction result of the climber for a specific posture where the distance between the marker and the true COM is maximal.

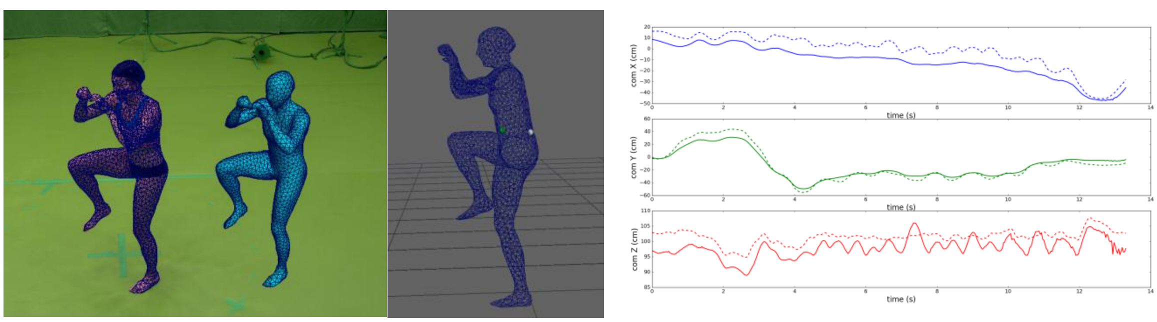

Figure 4 – Left: 3D reconstruction of the climber body – Middle: True center of mass (green) vs hips marker (white) – Right: temporal evolution of the true center of mass (solid line) vs the hips marker (dashed line)

Conclusion

In the context of speed climbing, we showed that it is possible to extract 3D information from the subject performance using two drones and calibration procedure from 3D geometry. From this 3D information, we derived profiles of the velocity components in the 3 axis of 3D space, vertical, lateral and orthogonal to the wall plane. These profiles can be used to interpret the posture of the climber and to suggest improvement when the vertical component is less dominant.

Using a full body 3D reconstruction of the climber in a laboratory environment, we showed that the approximation of the center of mass as fixed hips marker on the harness leads to a mean error of 12.5cm +/- 2,4 cm. As future works, it is thus planned to use the 3D avatar to perform markerless motion capture from the drone videos so that more accurate 3D information can be extracted during speed climbing performance.