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Development of a pipeline of 3D underwater motion capture: application to the analysis of horse swimming

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1. Introduction

Limbs and tendon injuries are primary causes of activity loss in racehorses and sport horses. Aquatic training is an effective method to maintain and strengthen the cardiorespiratory system while minimizing the impact of gravity on the musculoskeletal and joint systems. Although swimming pool training offers clinical advantages, the biomechanics of horse swimming has received little attention (Santosuosso et al. 2021) and remain poorly understood. Biomechanics research typically employs motion capture and analysis (Roberson et al. 2013). The objective of this study is to develop a pipeline for capturing and reconstructing underwater 3D motion, estimate the accuracy of the process and to apply it to the 3D motion of a horse during a complete swimming cycle.

2. Methods

2.1. Acquisition system

The acquisition system comprises six GoPro Hero 8 Black cameras, each capable of capturing 120 frames per second at a resolution of 2.7K. These cameras are strategically placed on one side of the swimming pool, as shown in Figure 1 – up, with overlapping fields of view to enable tracking over a distance of 2.6 meters (Figure 1 – bottom). On the horse, 24 anatomical markers were drawn by the veterinary team with cattle markers (Raidex) of contrasting colors with respect to the horse's color, on six anatomical locations on each limb: the scapula, the shoulder, the elbow, the carpus, the fetlock, and the hoof for the front limb (Figure 2 – left) and the tuber coxae, the hip, the stifle, the tarsus, the fetlock, and the hoof for the hind limb (Figure 2 – right). Only one side of the horse is visible to the cameras at each recording.

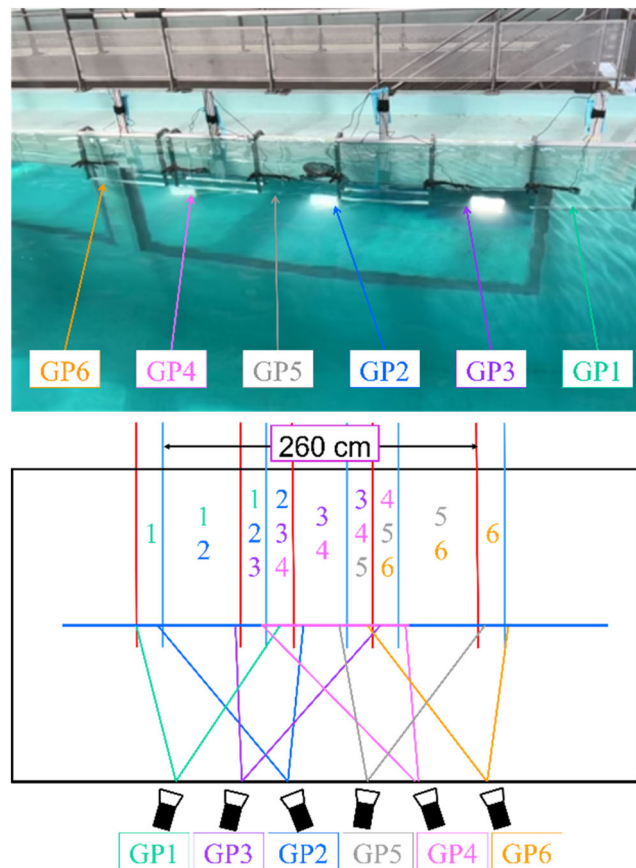


Figure 1. Camera disposition and field of view (GP = GoPro camera). the total field of view is around 260 cm, and each camera belongs to one (GP1 and GP6) or two pairs (GP2 to GP5) for the 3D reconstruction.

To date, the experiments have been conducted on four horses, representing 113 records.

2.2. Pre-processing of the video

Six preprocessing steps are necessary before performing the 3D reconstruction of the anatomical points:

- convert the videos to H264 format;
- segment the videos and synchronize them using successive shutdowns of the spotlights, which can be clearly seen on the videos;
- calibrate the cameras to determine their intrinsic and extrinsic parameters using images of a checkerboard and camera calibrator app (Matlab);
- correct the fisheye of the videos using camera parameters;
- compute the camera positioning with respect to each other using images of the checkerboard on each pairs of cameras and stereo-camera calibrator app (Matlab);
- track semi-automatically the anatomical points on the six videos using the video-labeler app (Matlab).

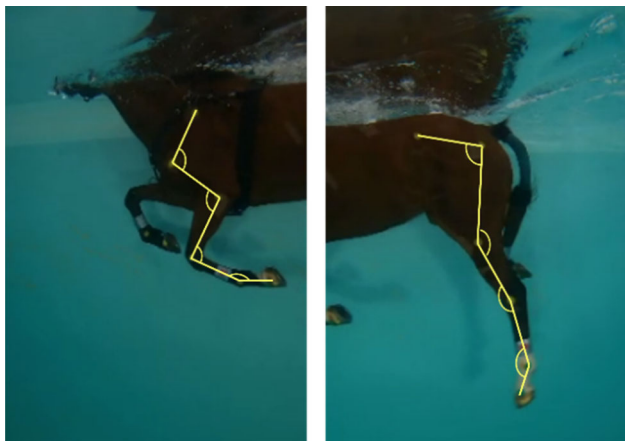


Figure 2. View of the 2nd and 5th camera at the same time. The anatomical points are from top to bottom: front limb (left): mid-length of scapular spine, shoulder, elbow, carpus, front fetlock and front foot. Hind limb (right): tuber coxae, hip, stifle, tarsus, hind fetlock and hind foot.

2.3. Post-processing of the video

By combining the tracked points and camera positioning, a 3D reconstruction is performed in local reference frames (reference frame of the first camera of each pair), using the Direct Linear Transformation (DLT) algorithm. A global reference frame of the swimming pool is established to enable the 3D reconstruction to be computed in a common reference frame with respect to the five pairs of cameras.

2.4. Error estimation

An error estimation has been computed on the checkerboard. We considered eight segments whose dimension is known by construction (between 34 and 60 mm) and five angles between 34 and 102°, which correspond to the dimension found on horses for the anatomical segments of the limbs. The absolute error is less than 10 mm for the reconstructed segments and less than 1° for the different angles computed.

3. Results and discussion

3.1. Horse reconstruction and angle computation

The 3D reconstruction of 24 anatomical points (12 on each side of the horse) allows for the computation of eight different angles of the front (Figure 2 – left) and hind (Figure 2 – right) limbs:

- (a) left: the shoulder angle formed by the anatomical points of the scapula, the shoulder and the elbow;
- (b) left: the elbow angle formed by the anatomical points of the shoulder, the elbow and the carpus;

Table 1. Value of the minimum and maximum computed values for the 8 angles.

| Front limb | Shoulder | Elbow | Carpus | Front fetlock |
|-------------|------------|-----------|-----------|---------------|
| Angle range | [100–125°] | [55–145°] | [60–180°] | [120–180°] |
| Hind limb | Hip | Stifle | Tarsus | Hind fetlock |
| Angle range | [60–110°] | [75–150°] | [50–170°] | [100–175°] |

- (c) left: the carpus angle formed by the anatomical points of the elbow, the carpus and the front fetlock;
- (d) left: the front fetlock angle formed by the anatomical points of the carpus, the front fetlock and the hoof of the front limb;
- (a) right: the hip angle formed by the anatomical points of the tuber coxae, the hip and the stifle;
- (b) right: the stifle angle formed by the anatomical points of the hip, the stifle and the tarsus;
- (c) right: the tarsus angle formed by the anatomical points of the stifle, the tarsus and the hind fetlock;
- (d) right: the hind fetlock angle formed by the anatomical points of the tarsus, the hind fetlock and the hoof of the hind limb.

The first results for the minimum and maximum values of the different reconstructed 3D angles are summarized in Table 1. Based on preliminary results from a single record, the joint range of motion is as follows: shoulder: 100–125°, hip: 60–110°, elbow: 55–145°, stifle: 75–150°, carpus: 60–180°, tarsus: 50–170°, front fetlock: 120–180° and hind fetlock: 100–175°.

These values have been compared to the values available for the three classical gaits – walk, trot and canter – (Back et al. 1997). It appears that the amplitude of the range of motion is greater for all angles during swimming, with greater maximum flexion and extension observed in both the front and hind limbs.

4. Conclusions

In summary, we have developed a comprehensive pipeline for capturing and analysing the joint movements of a horse's limbs during a full swimming stride. Our preliminary findings indicate a broader range of motion compared to traditional training, which could result in different muscle activation. This information could be valuable for muscle strengthening or rehabilitation purposes.

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