The 6th Joint International Conference on Multibody System Dynamics and
The 10th Asian Conference on Multibody System Dynamics
November 1-5, 2020, New Delhi, India

Use of Inertial Measurement Units for Filter-tuning in Optical Motion Capture

Florian Michaud, Urbano Lugris, Manuel Perez-Soto, Javier Cuadrado

Laboratory of Mechanical Engineering
University of La Coruña
Mendizabal s/n, 15403 Ferrol, Spain
[florian.michaud, urbano.lugris]@udc.es

Abstract
Optical and inertial motion capture have been extensively compared in the literature [1]. Generally, optical motion capture has been used to evaluate and/or improve the performance of its inertial counterpart [2]. While the optical alternative is currently the most accurate procedure, the noisy recorded trajectories make it necessary to apply filters in order to get acceptable values of velocities and accelerations. The point here is to find the suitable filtering level to eliminate the noise without losing relevant information [3]. The effect of filtering can be especially observed in the accelerations, obtained by double differentiation of the trajectories. Since inertia measurement units (IMU) directly provide accelerations (although expressed in the local reference system of the sensor), they are used in this work to adjust the filtering level that must be applied in the optical capture procedure so that a good correlation is obtained between the accelerations provided through both techniques.
First, a set of nine IMU (STT Systems, STT-IWS) was fixed on a wooden plate, where four reflective markers were also attached, as illustrated in Figure 1a. Starting with the plate on the floor, where it was kept for five seconds, it was manually moved around and, finally, put again in the original place. Data from both the IMU set and the optical system were recorded, so that the plate orientation provided by each IMU (based on gravity, magnetic North and gyroscope integration) during the motion could be plotted and compared with the plate orientation provided by the optical system, which was taken as reference, as shown in Figure 1b. Maximum errors of 19° with respect to the reference were found for the IMU, while differences of up to 8° were detected among IMU.

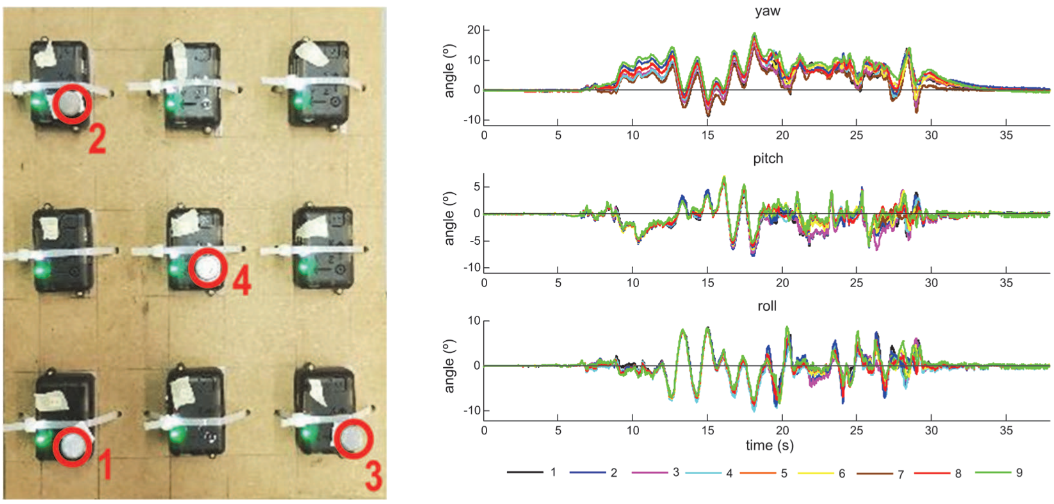

Figure 1: a) Nine IMU and four markers (circled in red) on a rigid plate; b) Orientation errors incurred by the nine IMU with respect to the optical system (reference).

Second, the gait analysis of a healthy subject was performed. Both thirty-six reflective markers in all his segments for optical motion capture and seven IMU at pelvis, thighs, shanks and feet for inertial motion capture were attached to the subject's body, as can be seen in Figure 2a. One additional marker was attached to each IMU so as to determine its local position in the corresponding segment. The results of the experiment with the wooden plate led to take the two following decisions: (i) since only seven IMU were required for gait analysis, the two worst devices were excluded; (ii) given the low accuracy achieved by the inertial sensors in the determination of their orientation, the rotation matrices needed to carry out the comparison between accelerations provided by the optical and the inertial system would be taken from the optical motion capture. The optical motion capture system was formed by 18 infrared cameras (Natural Point, OptiTrack FLEX 3 sampling at 100 Hz) along with the Extended Kalman Filter (EKF) based motion reconstruction method proposed in [4].

When using an EKF, instead of filtering the position data prior to numerical differentiation, a smoothing effect can also be achieved by tuning the process noise variance σ_a^2 : low variances limit the accelerations the system can reach at every time step, thus having a smoothing effect on the resulting position histories, while high variances allow for larger accelerations, so the system can follow the sensors (i.e. the markers) more closely, at the expense of introducing sensor noise into the reconstructed motion.

In Figure 2b, the acceleration history in local x direction measured by the IMU attached to the right foot (i.e. pointing from toes to ankle) is compared to the corresponding values obtained after application of different filtering parameters to the optical motion capture.

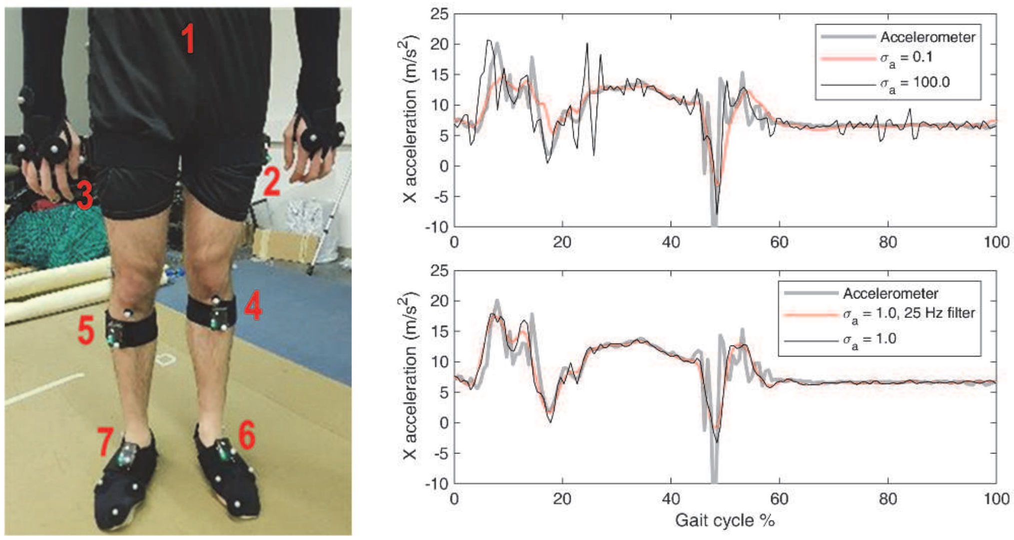

Figure 2: a) Markers and IMU (red numbers) attached to the subject's body for gait analysis; b) Acceleration history in local x direction of the IMU attached to the right foot, obtained with inertial system (grey) and optical system with different filtering levels.

In the top plot of Figure 2b, it can be seen that the EKF can lead to very noisy results for large values of σ_a (m/s^2 or rad/s^2, depending on the corresponding state variable), with acceleration spikes even when the foot is at rest. If the accelerations are limited by reducing the process noise variance, the signal gets smoother, but also delayed. A good compromise can be obtained by combining the EKF with a forward-backward 2nd order Butterworth filter, applied to the output signal before numerical differentiation. The results show that having accelerometer data can be very helpful as a reference for this tuning process, allowing to improve the accuracy of the accelerations obtained from the optical motion capture.

References

[1] Fleron, M.K.; Ubbesen, N.C.H.; Battistella, F.; Dejtiar, D.L.; Oliveira, A.S.: Accuracy between Optical and Inertial Motion Capture Systems for Assessing Trunk Speed during Preferred Gait and Transition Periods. Sports Biomechanics, Vol. 18, No. 4, pp. 366-377, 2019.

[2] Palermo, E.; Rossi, S.; Marini, F.; Patane, F.; Cappa, P.: Experimental Evaluation of Accuracy and Repeatability of a Novel Body-to-sensor Calibration Procedure for Inertial Sensor-based Gait Analysis. Measurement, Vol. 52, pp. 145-155, 2014.

[3] Skogstad, S.A.; Nymoen, K.; Hovin, M.; Holm, S.: Filtering Motion Capture Data for Real-time Applications. In Proceedings of the 13th Int. Conf. on New Interfaces for Musical Expression (NIME 2013), Daejeon, Korea, May 27-30, 2013.

[4] Lugris, U.; Vilela, R.; Sanjurjo, E.; Mouzo, F.; Michaud, F.: Implementation of an Extended Kalman Filter for Optical Motion Capture with Real–time 3D Visualization. In Proceedings of the 5th Joint International Conference on Multibody System Dynamics (IMSD), Lisbon, Portugal, June 24-28, 2018.