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An Eulerian-Lagrangian description for fluvial coarse sediment transport: theory and verification with low-cost inertial sensors.

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Fluvial sediment transport is controlled by hydraulics, sediment properties and arrangement, and flow history across a range of time scales. One reference frame descriptions (Eulerian or Lagrangian) yield useful results but restrict the theoretical understanding of the process as differences between the two phases (liquid and solid) are not explicitly accounted.

Recently, affordable Inertial Measurement Units (IMUs) that can be embedded in coarse (100 mm diameter scale) natural or artificial particles became available. These sensors are subjected to technical limitations when deployed for natural sediment transport. However, they give us the ability to measure for the first time the inertial dynamics (acceleration and angular velocity) of moving sediment grains under fluvial transport.

Theoretically, the assumption of an ideal (IMU), rigidly attached at the centre of the mass of a sediment particle can simplify greatly the derivation of a general Eulerian-Lagrangian (E-L) model. This approach accounts for inertial characteristics of particles in a Lagrangian (particle fixed) frame, and for the hydrodynamics in an independent Eulerian frame. Simplified versions of the E-L model have been evaluated in laboratory experiments using real-IMUs [Maniatis et. al 2015].

Here, experimental results are presented relevant to the evaluation of the complete E-L model. Artificial particles were deployed in a series of laboratory and field experiments. The particles are equipped with an IMU capable of recording acceleration at ± 400 g and angular velocities at ± 1200 rads/sec ranges. The sampling frequency ranges from 50 to 200 Hz for the total IMU measurement.

Two sets of laboratory experiments were conducted in a 0.9m wide laboratory flume. The first is a set of entrainment threshold experiments using two artificial particles: a spherical of D=90mm (A) and an ellipsoid with axes of 100, 70 and 30 mm (B). For the second set of experiments, a spherical artificial enclosure of D=75 mm (C) was released to roll freely in a (> threshold for entrainment) flow and over surfaces of different roughness. Finally, the coarser spherical and elliptical sensor- assemblies (A and B) were deployed in a steep mountain stream during active sediment transport flow conditions.

The results include the calculation of the inertial acceleration, the instantaneous particle velocity and the total kinetic energy of the mobile particle (including the rotational component using gyroscope measurements). The comparison of the field deployments with the laboratory experiments suggests that E-L model can be generalised from laboratory to natural conditions. Overall, the inertia of individual coarse particles is a statistically significant effect for all the modes of sediment transport (entrainment, translation, deposition) in both natural and laboratory regimes.

Maniatis et. al 2015: “Calculating the Explicit Probability of Entrainment Based on Inertial Acceleration Measurements”, J. Hydraulic Engineering, 04016097