Advances in Field Deployable Instrumented Particles for the Study of Alluvial Transport Mechanisms

Brandon J. Dillon, Kyle Strom

Kelso Baker Environmental Hydraulics Laboratory

VIRGINIA TECH™

Abstract

As a result of work performed in the Kelso Baker Environmental Hydraulics Laboratory at Virginia Tech, a field deployable, instrumented particle has been created for use in the study of incipient motion. To our knowledge, it is the first such particle that combines pressure sensors, internal accelerometers, a gyroscope, and erodibility into a single compact package. With this instrument we hope to answer the following questions:

- What is the relative contribution of lift vs. drag forces in erosion processes?
- What types of hydrodynamic phenomena contribute to sliding or rolling entrainment modes?
- Does the degree of relative submergence effect the type of coherent structures present?
- Does the interaction between sediment and turbulence change with relative submergence?

Instrument Design

This particle has been designed to match the size and weight of gravels commonly found in mid-Appalachian fluvial watersheds. Its diameter is 19mm (0.75 in) and it has a specific gravity of 2.4 with a non-eccentric center of mass to aid in studying the mode of entrainment (*e.g.* sliding vs rolling). Pressure forces are measured through the use of six prepolarized film transducers that are fully integrated into the particle (no external tubes are required) while the dynamics of the particle are measured by a three-axis MEMS accelerometer and a one-axis MEMS gyroscope.

The transducers are powered and signals are transmitted through a sixteen-conductor, 46 AWG cable that measures 0.9 mm (0.036 in) in diameter and is designed to "spool out" during an entrainment event – later acting as a tether to prevent the loss of the particle. Furthermore, the package is waterproof and has shown a remarkable resistance to salts and solvents.

The components that are used to construct the particle are low cost. On average, each instrument requires around $20 worth of materials. The assembly process, however, is tedious and calls for a large time investment. Each particle can require up to four days to create. The work is performed primarily under a stereo microscope and requires a high level of fine motor control. Failure at this stage is common on account of the low tolerance to mechanical stress the 46 AWG wires possess. When the package is secured and sealed, the particle becomes resistant to mechanical abuse.

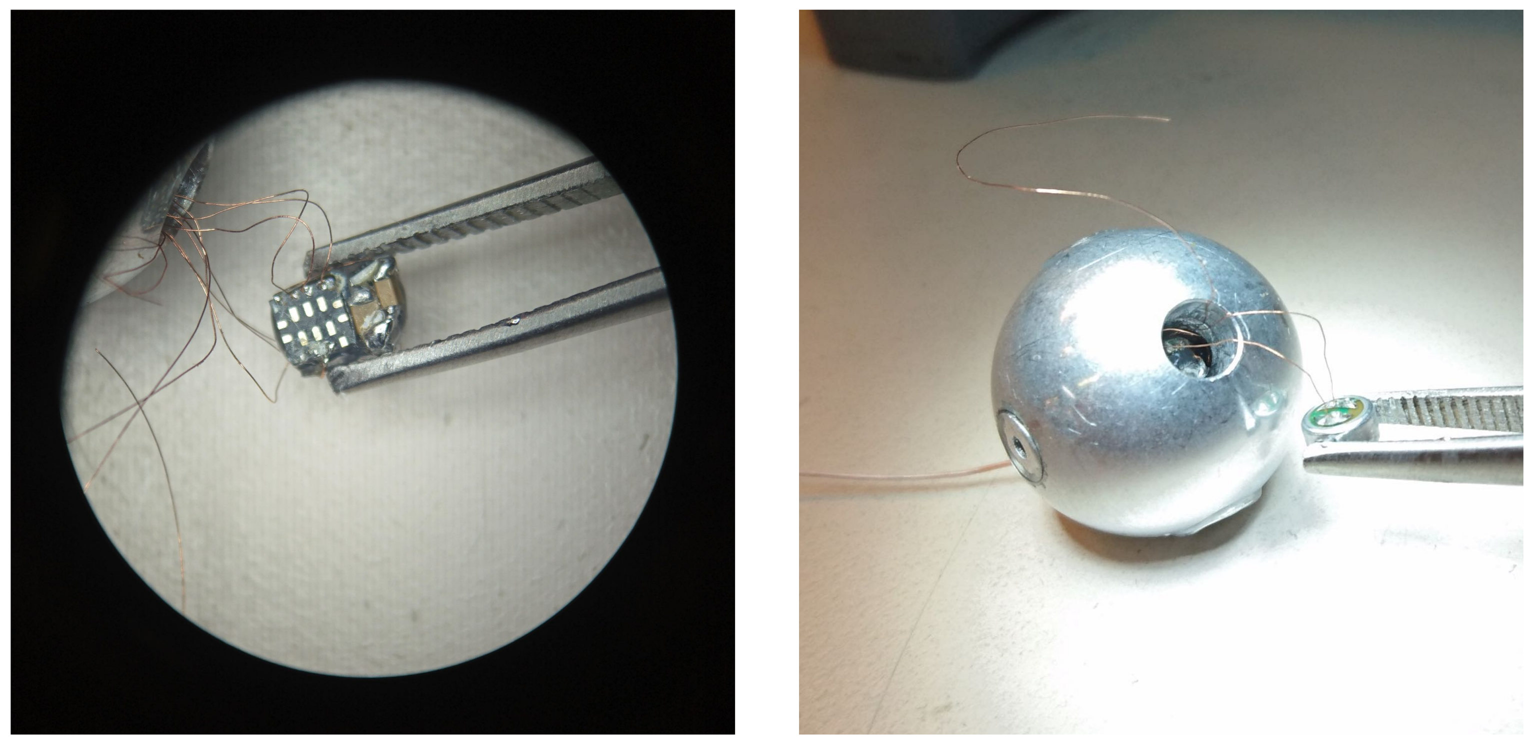

Figure 1: The Inertial Package (2.5 x 3 x 6 mm) and Pressure Transducer (4 x 2.8 mm)

Field Measurement Capabilities

The miniaturized cable is buried in a small, sub-surface channel of play sand to protect it from physical damage and is routed up though the armor layer to the instrumented particle. A small loop of wire is formed inside of a void below the particle provided by the armor layer. In this way, during an entrainment event wire slack is provided to allow the particle to accelerate naturally and follow the course it would have taken without being tethered.

Figure 2: The Instrumented Particle *In-Situ* with Wire Loop Visible

The system also makes use of a heretofore unpublished ruggedized optical fiber PIV system developed in conjunction with the instrumented particle project. This additional system allows high quality PIV (14.2 mJ / pulse @ 0.02 mm-Rad – 1000 fps) to be deployed alongside of the instrumented particle and provides spatial information on the nature of the coherent structures which are interacting with the particle. Like the instrumented particle, the sheet forming optical package is waterproof and is also specifically designed to create the laser fan while in contact with water. Because the laser power is delivered via an optical fiber, this system does not affect the free surface while in use.

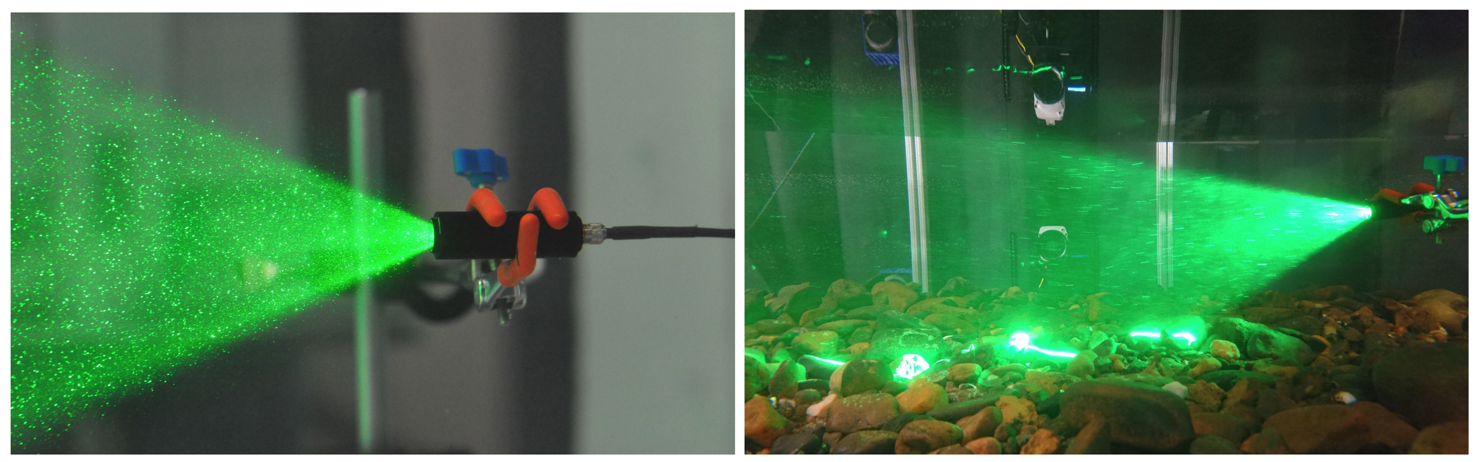

Figure 3: The Optical Fiber Sheet-Forming Package in Use

Results

To date, the instrumented particle has undergone tests in a laboratory flume filled with bed material sourced from the location of its intended use – a gravel-lined reach of the New River in Virginia. Below are the results from an entrainment event that was captured with the combined instrumented particle and PIV systems.

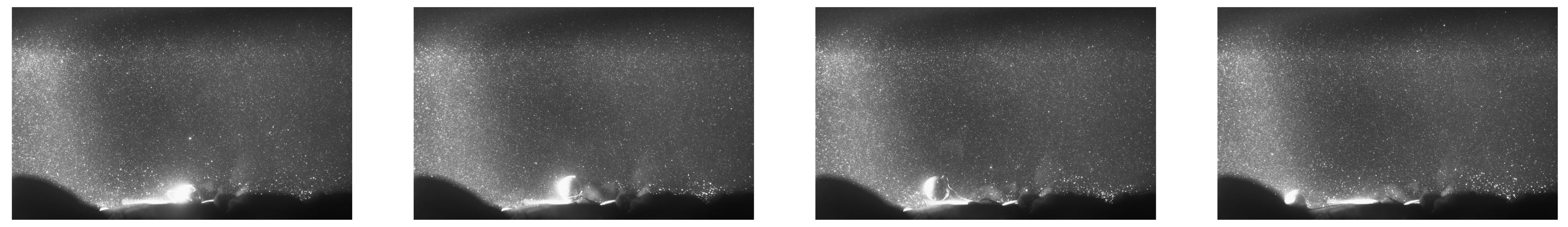

Figure 4: The Progression of a Rolling-Type Entrainment Event with Saltation

The vertical red and green lines denote the beginning and tethered-arrest of the entrainment event. Take note of the in-phase lift and drag peaks at the start of the event. While there were stronger lift and drag events prior to the incipient condition, none were phase aligned and simply resulted in a "rocking" of the particle – the signature of which can be seen in the accelerometer data.

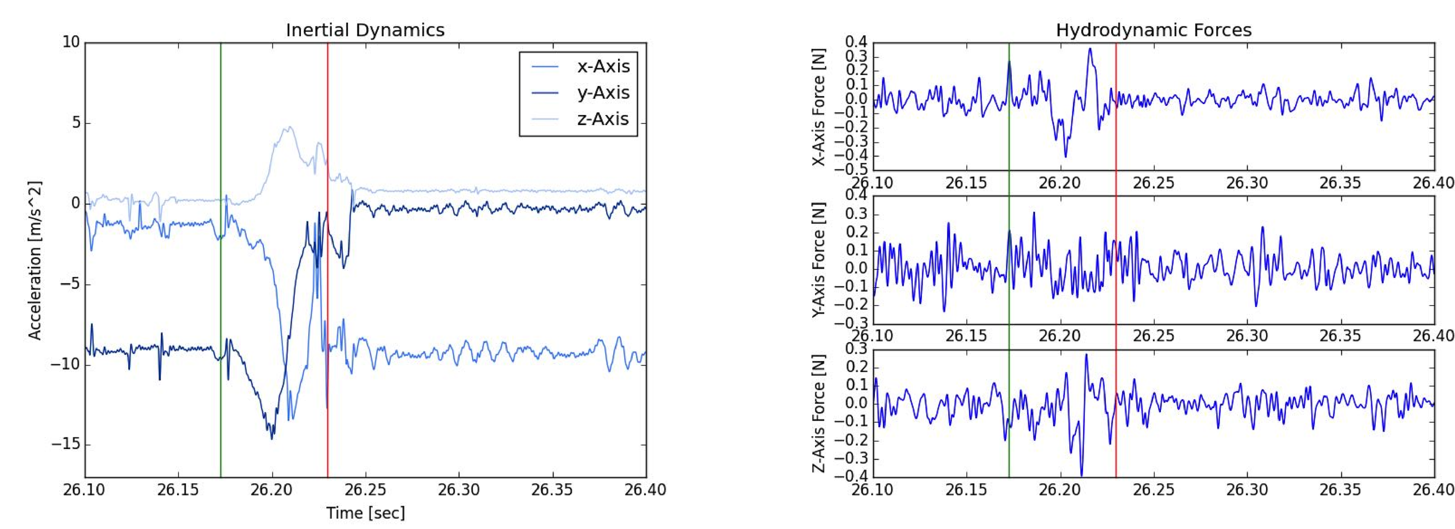

Figure 5: Time Histories of the Inertial and Pressure Data Captured During the Entrainment Event

Next Steps

The PIV system has been tested *in-situ* and performs as expected. Preparations for the field deployment of the instrumented particle are underway.

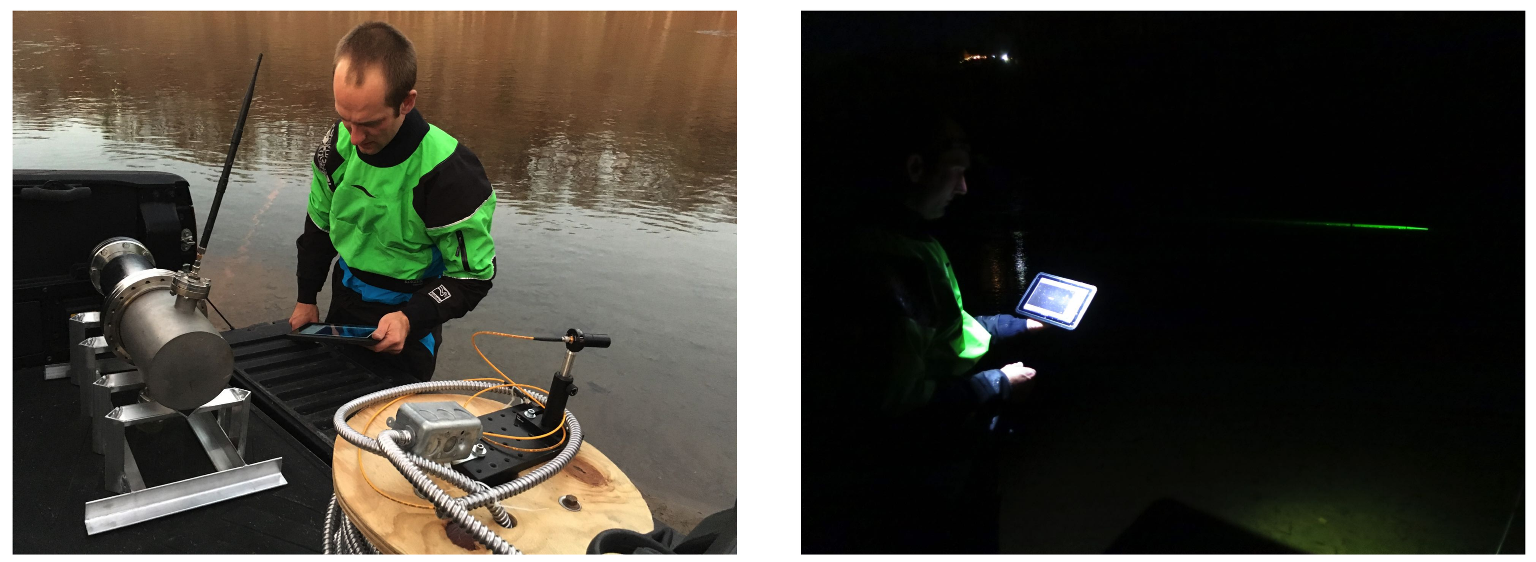

Figure 6: Field Deployment of the PIV System