Application of a line laser scanner for bed form tracking in a laboratory flume

T.V. de Ruijsscher*[1], S. Dinnissen[1], B. Vermeulen[2], P. Hazenberg[1], A.J.F. Hoitink[1]
[1] *Wageningen University & Research, Department of Environmental Sciences, Hydrology and Quantitative Water Management Group, P.O. Box 47, 6700 AA, Wageningen, the Netherlands*
[2] *University of Twente, Department of Water Engineering and Management, Faculty of Engineering Technology, P.O. Box 217, 7500 AE, Enschede, the Netherlands*
** Corresponding author; e-mail: timo.deruijsscher@wur.nl*

Introduction

In order to develop a measurement method that is fully non-invasive and able to capture the short timescale bed-form dynamics, tests have been performed with single-beam (Visconti et al., 2012) and multi-beam (Friedrichs and Graf, 2006; Peña González et al., 2007) laser scanners. However, these studies have only focused on a laser beam travelling vertically downward up till now. In the present study the full range of beams emitted by a multi-beam laser is taken into account, and corrections are quantified and performed in order to reduce the errors due to e.g. refraction. The applied corrections are used for measuring dunes and alternate bars under flowing water conditions.

Methods

The here proposed bed-form measurement method consists of a line laser and a 3D-camera with Gigabit Ethernet (SICK, 2012), both mounted on a measurement carriage that can move on fixed rails along the flume. The beam swath angle of the laser array is 50.0°, covering a width of 419 mm of the bare flume bottom. This width decreases evidently when a layer of sediment is present. The projected laser line is oriented perpendicular to the flow direction, and the camera is looking at an angle (see Fig. 1). The bed profile is measured by means of triangulation. Because of the limited width of the laser beam swath, multiple parallel (partly overlapping) tracks are used to measure the whole width of the flume (1.2 m).

Four consecutive series of experiments are performed, viz. measurement of the bottom profile of 1) an empty flume (no water, no sediment), 2) a flume with still water, 3) a flume with flowing water, and 4) a flume with a movable bed consisting of sand with a density of $\rho_s = 2650\ \mathrm{kg\ m^{-3}}$ and a size of $D_{50} = 0.719$ mm and $D_{90} = 0.962$ mm.

Corrections are performed both for errors resulting from internal camera calibration and for refraction at the air-water interface.

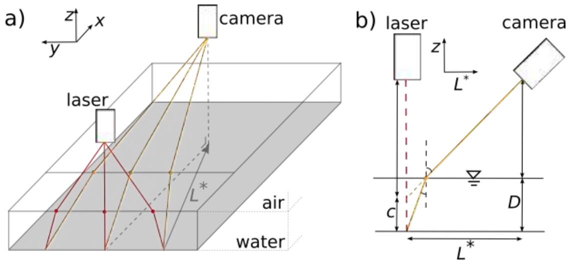

Figure 1. a) Overview of the experimental set-up. Red lines indicate transmitted laser beams and yellow lines indicate reflected laser beams, measured by the camera. b) Side view of the flume showing the reflected laser beams. The refraction correction c and the water depth D are indicated.

Outliers and missing values have to be corrected for in the moving bed experiment by applying a smoothing and interpolating algorithm. Because of the irregularly spaced nature of the retrieved data, an algorithm that does not need interpolation to a regular grid beforehand is preferred. LOESS, a robust locally weighted regression algorithm (Cleveland, 1979) appears to be an appropriate choice (Vermeulen et al., 2014). This fitting algorithm is based on a polynomial fit to the data using weighted least squares. An example of the effect of LOESS fitting to data is shown in Fig. 2, showing clearly the 3D nature of the LOESS algorithm.

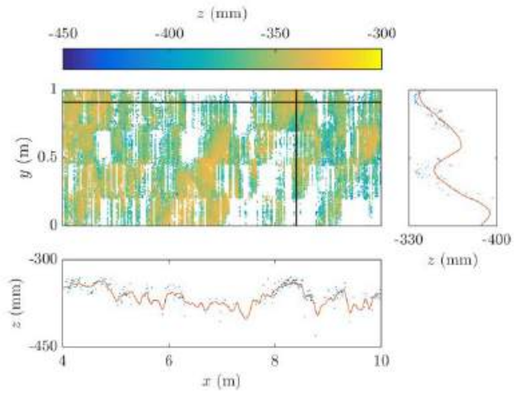

Figure 2. An example of the effect of LOESS fitting. The colour plot shows the measured bed level at the end of the moving bed experiment. Black lines indicate along-track and cross-track cross-sections, which are highlighted in the bottom and right plot, respectively. Measured values are shown in blue dots and the fitted profile as a red curve.

Results

For measurement of the bare bottom with flowing water of different discharges, correlations between the mean absolute measurement error $|\bar{\epsilon}|$, coefficient of variation of the measurement error $\sigma_\epsilon/|\bar{\epsilon}|$ and percentage of missing values m, and both water depth D and flow velocity u are shown in Fig. 3. It can be seen that $|\bar{\epsilon}| \propto u$, $\sigma_\epsilon/|\bar{\epsilon}| \propto D$ and $m \propto D$.

Besides the interpolating effect of the LOESS algorithm as shown in Fig. 2, it is also used to filter out bed forms of a specific spatial scale. Fig. 4 shows for instance the application of a LOESS algorithm with a span area of 2.0 m^2, revealing an alternating bar pattern, with the bars moving downstream.

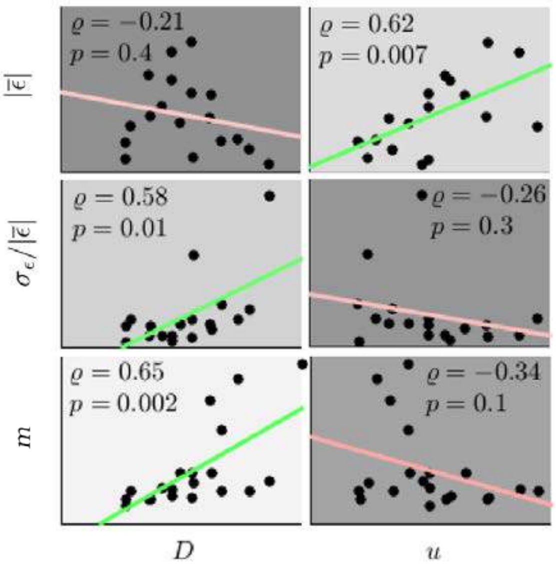

Figure 3. Flowing water correlations between absolute mean residual error $|\bar{\epsilon}|$, coefficient of variation $\sigma_\epsilon/|\bar{\epsilon}|$ and the percentage of missing values m, and both water depth D and flow velocity u. Both correlation coefficient ρ and the p-value are given, with the latter reflected by the background intensity.

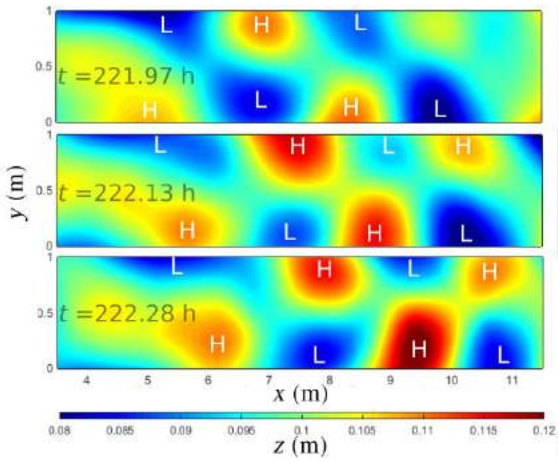

Figure 4. Measured bed profile at three different times, after applying a LOESS filter with a span of 2.0 m^2. 'H' indicates a relatively high and 'L' a relatively low bed level.

Conclusions

A line laser scanner turns out to be a good replacement for existing bed form measurement techniques (acoustic techniques, single beam lasers, et cetera), resolving part of the difficulties of these widely used methods.

Flowing water conditions initiate larger measuring errors. Moreover, the relative spread of the measurement error increases with increasing water level. Despite these effects and the relatively large amount of missing values, satisfying results are obtained in a pilot with a moving sand bed. Especially when a robust locally weighted regression fit (LOESS) is applied to take outliers and missing values into account, the potential for bed form studies under laboratory conditions is huge compared to more traditional methods. Bed forms can be tracked during the experiment and there is no need to disturb the flow while measuring.

When lightweight sediment is used, like polystyrene, a decrease in the measurement error and in the percentage of missing values is expected compared to the results shown in this study, based on the limited flow velocity needed for bed forms to be created.

Acknowledgements

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The numerical implementation of the LOESS algorithm in Matlab and C++ is open source and can be found on https://github.com/bartverm.

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