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DRONE-DRIVEN SURFACE VELOCITY MEASUREMENTS IN NATURAL RIVERS

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ABSTRACT

Predicting the flow in rivers is an important concern regarding potential damages induced by floods. In order to assess the reliability and accuracy of numerical simulation tools, detailed field or laboratory data are needed. The available methods can be classified into intrusive and non-intrusive methods depending on the intrusion of the device in the flow, or pointwise and field methods, for data acquired at a single position in the flow or over a larger area. The use of imagery techniques as non-intrusive methods providing field data is increasing for different types of applications. This paper explores the use of drone-driven LSPIV (Large Scale Particle Image Velocimetry) to measure the surface velocity. From these data, the aim is to obtain discharge measurements in the flow. However, the application of these methods still presents numerous challenges. The case studied in the present paper concerns field measurements on eight different rivers. The results obtained using LSPIV and other more classical methods such as current meter (mechanical method) for velocity are compared. The integral of differences between the two methods has a range between 0 and 7% with a mean of 3.28 % and a standard deviation of 2.57 %.The results show promising agreement between both measurement techniques and highlight the perspectives for future field applications of the combined photogrammetry and LSPIV method.

Keywords: Discharge measurements, LSPIV, Steady flow, Non-intrusive techniques

1 INTRODUCTION

A wide range of techniques exists for measuring the discharge in a river, one of the most widely used being the stage-discharge relation based on a water-level measurement. However, during flood events, the measured water level often exceeds the maximum value of the rating curve, yielding inaccurate discharge estimates that are required to characterize floods and evaluate potential damages. Other traditional measurement devices such as current meters or ADCP can be damaged during floods, especially when the river presents a strong velocity and floating debris. Field data collection during floods is thus a challenging task that requires an adapted methodology. Such field data are of paramount importance e.g. to assess the reliability and accuracy of numerical simulation tools aimed at designing flood protection measures.

Among the non-intrusive techniques able to provide data even in extreme situations, one can find the imagery based techniques such as LSPIV (Large-Scale Particle Image Velocimetry), relying mainly on surface-velocity measurements by tracking the motion of floating tracers or the motion of water if it is visible in a sequence of images (Hauet, 2014).The results gives an almost continuous 2D velocity field representing the surface velocities of the river. One can estimate the mean velocities from the surface velocities using a correction factor for the surface velocities and a velocity index to transform these surface values into depth-averaged values (Hauet., 2006). LSPIV results, combined with the knowledge of the bathymetry, can then give an estimation of the discharge (Bento et al., 2017).

In this work, the LSPIV technique is applied on images acquired by a drone flying over different small river reaches. The measurement procedure, including drone stabilization, is first presented. Then, field applications are presented and the drone-driven measured velocities are compared to other more classical techniques. Finally, conclusions are drawn on the applicability of the method and on the required extensions to obtain the discharge from these velocity measurements.

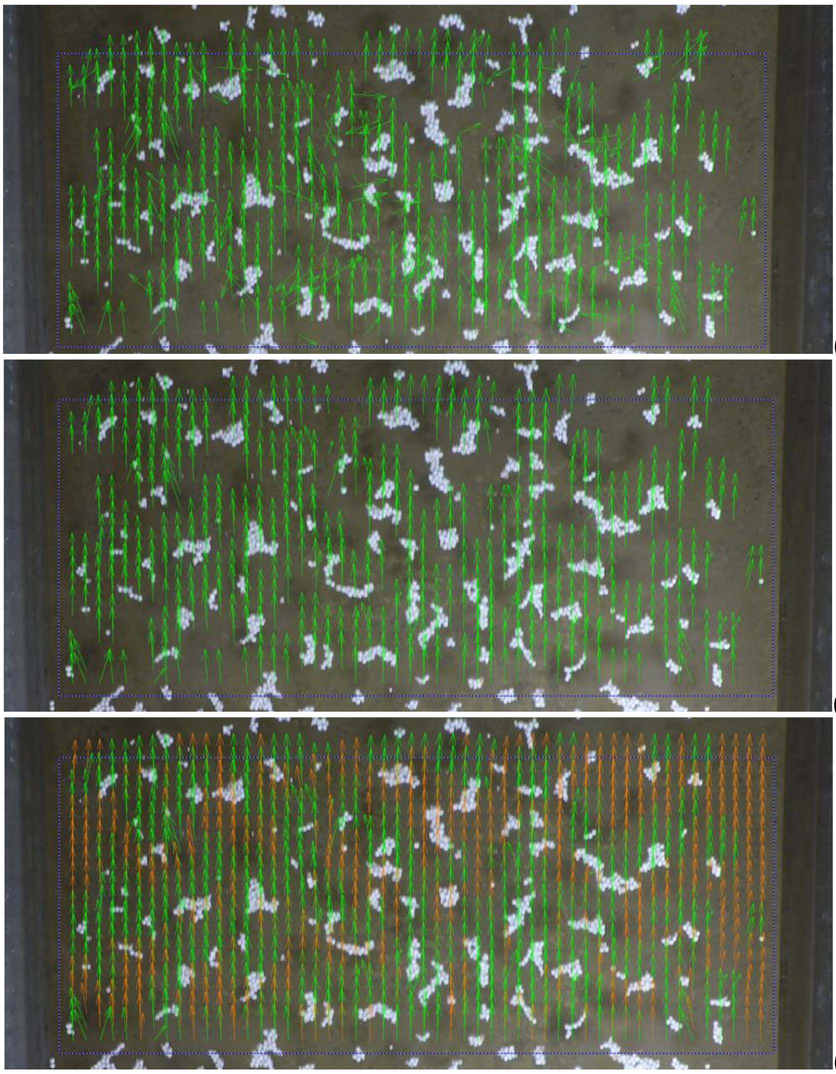
2 DRONE-DRIVEN LSPIV

2.1 Particle Image Velocimetry for surface velocity

The purpose of Particle Image Velocimetry (PIV) is to calculate 2D velocity fields in a flow from a series of pairs of images of this flow, each pair of images being distant by a small time step dt (Adrian, 1991). The principle of PIV is to detect and quantify the displacement of tracers between two successive images. When applied to obtain a vertical velocity field in the flow, neutrally buoyant tracers have to be used (e.g. Aleixo et al., 2011, Fent et al., 2019). For surface velocities measured in natural rivers, the LSPIV (Large Scale Particle Image Velocimetry) is used, which is PIV adapted to wide surfaces such as rivers with floating tracers, assuming that they move at the same velocity as the water. Therefore, too light and large tracers should be avoided as they can be influenced by wind or drag effects.

In the present work, small wooden elements are used with a size on the images of about 2-8 pixels, allowing good identification. Images are acquired at a frequency of 24 frames per second. The software used for the analysis of the images is PIVLab (Thielicke, 2010) and the process can be summarized in six distinct steps, illustrated in Figure 1 obtained from preliminary tests in the lab with white polystyrene tracers:

1. Seeding of the free surface with tracers and recording the images
2. Image pre-processing to maximize the visibility of the tracers
3. PIV Analysis to obtain a first vector velocity field from a cross-correlation (Figure 1a)
4. Post-treatment consisting in the validation of the velocity vectors and deletion of obvious outliers (Figure 1b)
5. Conversion of units, from a velocity in *pixels/frame* to a velocity in *m/s.*
6. Averaging of the vectors in order to obtain a complete and continuous velocity field (Figure 1c) using the *boundary value solver* (Thielicke, 2010)



(a)
(b)
(c)

Figure 1. PIV analysis using PIVLab for a laboratory case: (a) first velocity field obtained from the PIV analysis, (b) removal of obvious outliers (areas of outliers are highlighted) and (c) continuous velocity field obtained after vector interpolation.

2.2 Drone-driven LSPIV and image stabilization

When the images are acquired from a drone flying over the river, image stabilization is required to avoid spurious velocities. Indeed, even though drones are equipped with automatic stabilization procedures, there is always a residual motion as can be seen in Figure 2 (left panel): two successive images of a known field at rest are processed using PIVLab and the resulting velocity vectors are illustrated in the lower image. Therefore, the PIVLab was adapted (Bia and Somers, 2018) to avoid the appearance of such spurious velocities. A stabilization procedure was included in the image analysis before the pre-processing of the images, based on movement corrections after identification of fixed points on the images, either manually placed elements or natural elements clearly identifiable on the images. The result of the stabilization procedure can be seen in Figure 2 (right panel): the absence of velocity vectors testifies the efficiency of the stabilization. The mean velocity of the non-stabilized frame is 0.1002 m/s while the mean velocity of the stabilized one is 0.6x10-3 m/s. This value allows us to neglect the drones' movements after stabilizing the videos.

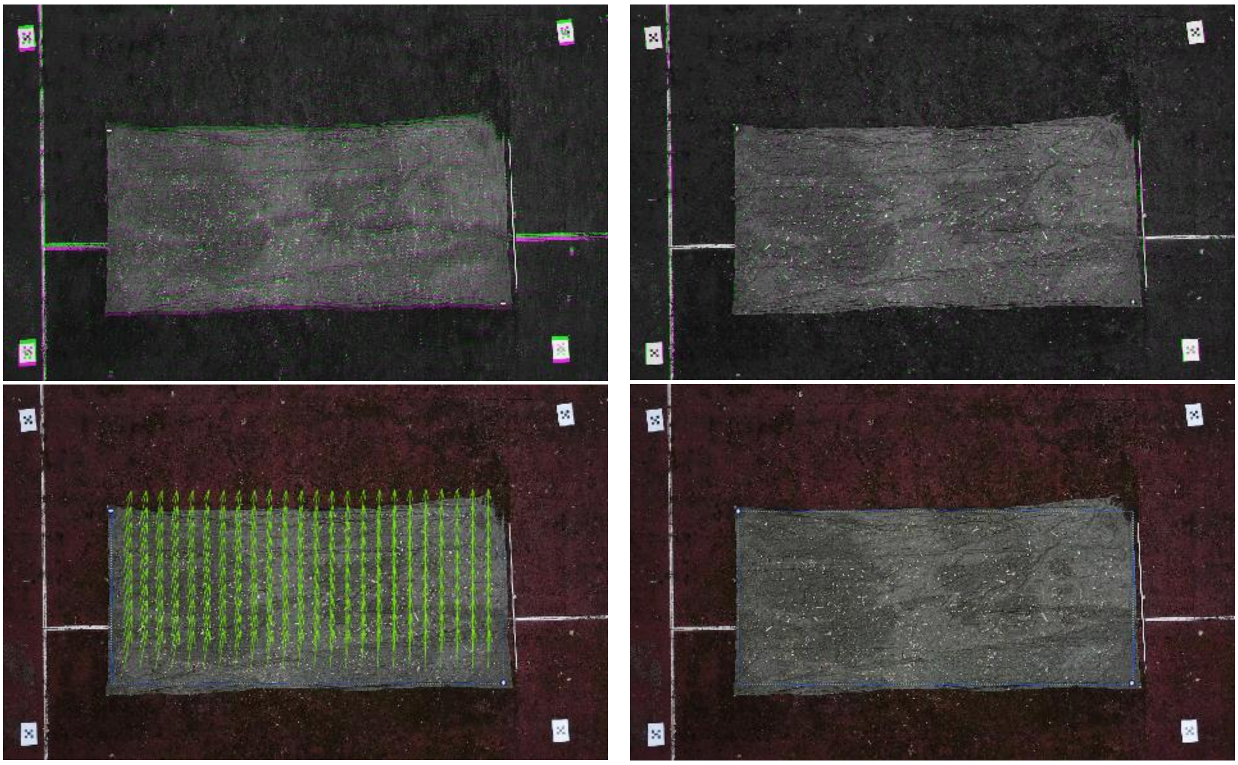


Figure 2. Left: Motion between two non-stabilized images, temporal spacing of 1 sec and their corresponding PIV results (mean velocity of 0.1 m/s). Right: Motion between two stabilized images and their corresponding PIV results (mean velocity of 0.6x10-3 m/s).

2.3 Velocity correction factor

The surface velocities obtained using the drone-driven LSPIV techniques are compared to measurements obtained using a magnetic induction current meter OTT MF Pro. The surface velocity field as processed by PIVLab is illustrated in Figure 3. The landmarks visible in the Figure are used to calibrate the transformation from pixel to real-world coordinates. The line between the two red squares indicate the cross-section over which the current meter measurements are obtained.

Figure 3. Velocity measurement using PIVLab

The comparison between the LSPIV and OTT MF-Pro measurements is illustrated in Figure 4.

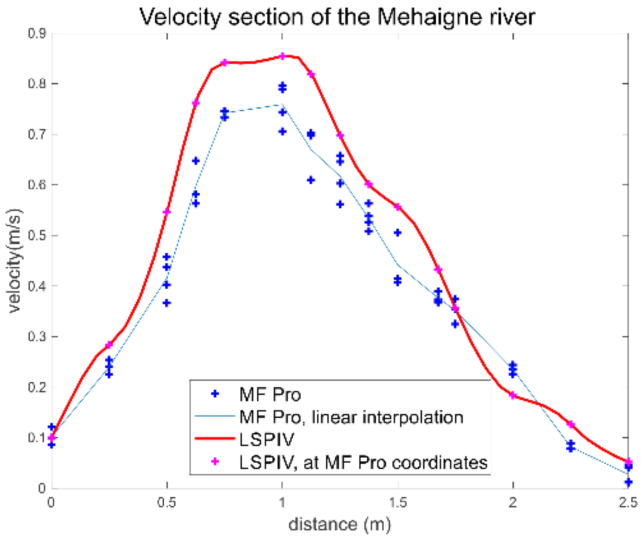


Figure 4: Velocity according to the cross section. Results from the Mehaigne River. The x-axis represents the cross section from the left to the right riverbank. The blue line is a linear interpolation of the MF Pro results

It can be observed that the LSPIV method tends to overestimate the surface velocity comparing to the MF Pro current meter. This process has been repeated on eight different rivers and we observe systematically an overestimation of the surface velocity by the LSPIV-method. This overestimation was almost the same for each of the considered rivers (Table 1).

A global correction factor was then found using an error optimization procedure to find the value minimizing the error for the eight rivers (Figure 5). Different methods were applied, such as the mean of differences, the difference of means and the difference of integrals of errors, yielding the three different curves of Figure 5. From these three curves, the correction factor giving the global minimum of errors was found to be 0.86. This value will be applied in the analysis presented hereafter.

The systematic overestimation of the LSPIV compared to the MFPro could be generated by the position of the current meter. The sensor has to be completely submerged in order to measure a velocity. The measurement is thus taken below the surface but close to it. The velocity measurements could be thus lower than the surface velocity and explain the overestimation of the LSPIV method. The complete submersion of the sensor is at the discretion of the operator and could generate a bias of the MFPro measurements. This will be further investigated in future studies.

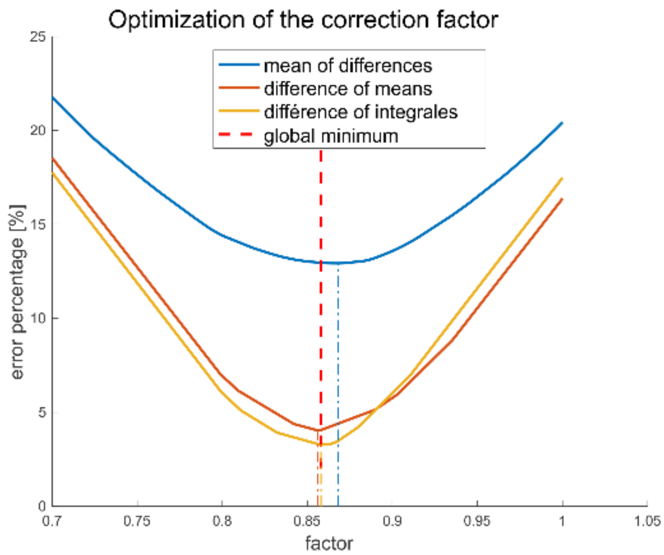


Figure 5. Curves presenting the mean of the errors of eight rivers according to the correction factor.

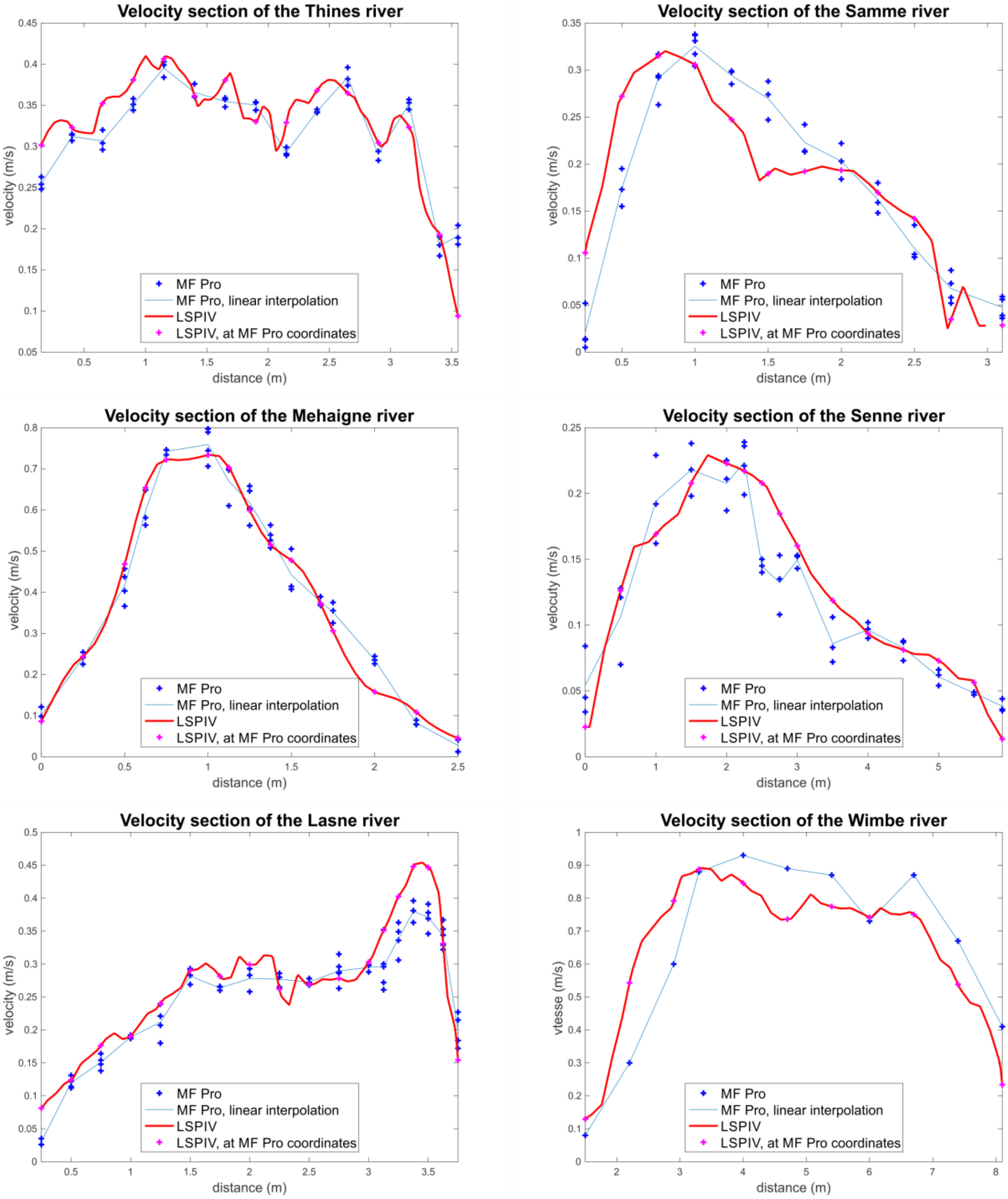
Table 1. Optimal correction for eight rivers

River	Thines	Samme	Mehaigne	Senne	Lasne	Wimbe	Almache	Lesse
Optimum	0.84	0.86	0.86	0.81	0.8	0.89	0.94	0.9

3 RESULTS OF THE FIELD MEASUREMENTS

3.1 Results of the 8 study sites

The drone-driven LSPIV methodology has been applied to the eight surveyed rivers. For each river, the correction factor 0.86 was applied and the results are compared to measurements obtained using the OTT MF-Pro close to the water surface. The results are illustrated in Figure 6. A good agreement of the different measurements can be observed, even though the surface-velocity fields appear quite complex for some of the study sites.



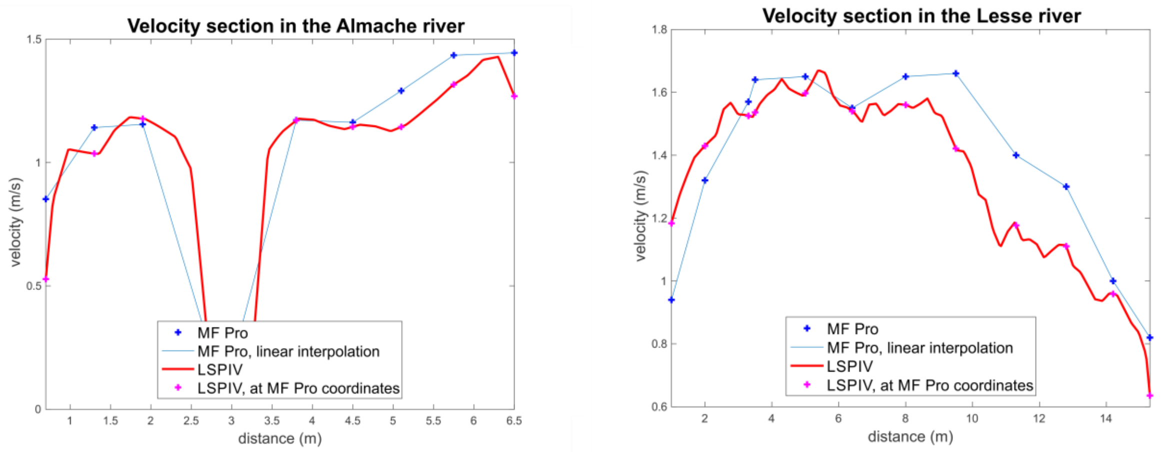


Figure 6. Surface velocity in the different rivers, measured using the drone-driven LSPIV technique and compared to the OTT MF-Pro measurements

Table 2 gives a summary of the integrals differences for the eight rivers. The mean of the difference of the integrals differences is 3.28% with a standard deviation of 2.57%.

Table 2. Error estimates using the correction factor of 0.86

RIVER	DIFFERENCE OF INTEGRALS [%]
Thines	3.1
Samme	0.59
Mehaigne	1.07
Senne	5.81
Lasne	7.38
Wimbe	2.44
Almache	0.04
Lesse	5.79

3.2 Extension to discharge measurements

The main perspective of this research is to obtain the discharge in a river using surface velocity measurements. The methodology was thus tested on a new river section and the discharge estimate was compared to the discharge measurement provided by the ministry of public works (SPW – Servce Public de Wallonie). A new section of the Lasne River was considered and the surface velocity measurements are illustrated in Figure 7. The figure again compares the results of the surface velocities obtained with the OTT MF-Pro current meter to the ones calculated with the LSPIV method using the correction factor 0.86. The error was found to be 2%.

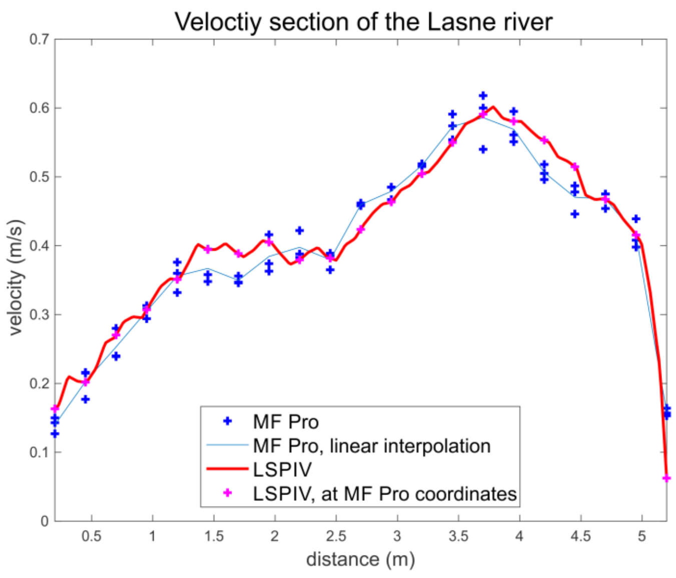


Figure 7. Results obtained for the Lasne River, with the correction coefficient 0.86

Then, to determine the discharge in this section, the bathymetry was measured manually and is illustrated in Figure 8 where the 0-elevation on the y-axis corresponds to the free surface elevation. To calculate the discharge, the section is divided into a series of vertical slices. The area of each slice is multiplied by the local depth-averaged velocity and by summing all these values, the total discharge in the cross-section is obtained. To apply this procedure, the surface velocity over each portion of the cross-section has to be transformed into a depth-averaged velocity. This is achieved by applying a velocity index of 0.85 as suggested by Hauet (2006).

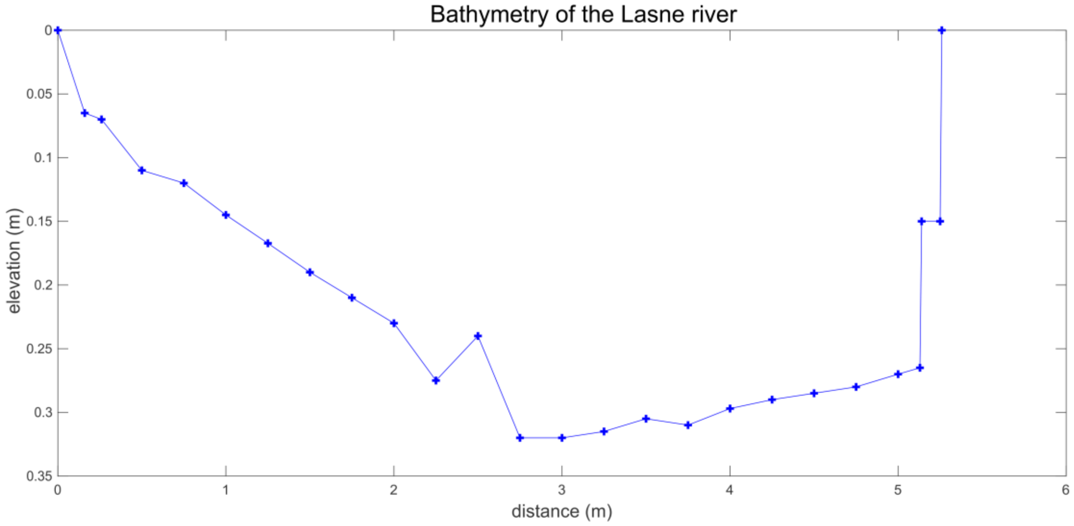


Figure 8. Bathymetry of the Lasne river.

The discharge is thus calculated from the known bathymetry and the LSPIV measurements where the correction factor 0.86 and the velocity index 0.85 are applied. The resulting error on the discharge estimate is 4.3% compared to the official real-time measurement provided by SPW.

4 CONCLUSIONS

This paper presents the application of a drone-driven LSPIV technique to measure the surface velocity in natural rivers. A key element in the process is the image stabilization procedure that enables to avoid spurious velocities induced by the small drone movements when in stationary flight.

From the field measurements carried out on eight different rivers, it was observed that the drone-driven LSPIV tends to overestimate the velocities. An average correction factor was determined, allowing to reach an accuracy in the surface-velocity measurements less than 3 %.

The procedure was then applied in an exploratory way to discharge measurements in a new, non-calibrated, river section for which the bathymetry was measured. A first discharge estimate was obtained with an error less than 5%.

Future work will be conducted to obtain more discharge measurements. In particular, cross-section shapes from the SPW data base will be used in order to assess the potential use of the methodology during floods, when direct measurements in the river are impossible.

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