On the use of LSPIV-based free software programs for the monitoring of river: testing the PIVlab and the FUDAA-LSPIV with synthetic and real image sequences

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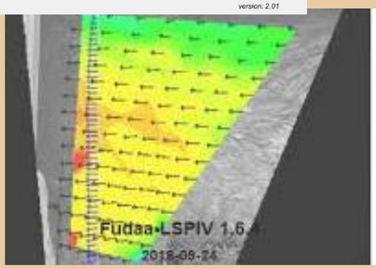
Advances in river monitoring and modelling: data-scarce environments, real-time approaches, Inter-comparison of innovative and classical frameworks, uncertainties, Harmonisation of methods and good practices

Abstract

River monitoring is recently experiencing a radical change thanks to the rapid development of new image-based techniques. The non-intrusiveness of optical techniques provides important advantages with respect to traditional methods, allowing for measures even in adverse circumstances. The method here investigated is the **large-scale particle image velocimetry** (**LS-PIV**). This is essentially based on the dynamic analysis of a tracer floating on the liquid surface through a pattern recognition technique based on cross-correlation between consecutive frames, recorded also with commercial digital cameras. Aim of this work is to analyze and compare under different operative conditions two of the most common free software packages based on the LSPIV technique: the **PIVlab** and the **FUDAA-LSPIV**. The test is carried out by analyzing sequences of both synthetic images, opportunely generated by an Image Sequence Generator, and real frames, acquired by field surveys in two natural rivers of Sicily (Italy).

Objectives

- Study of limits and potentialities of two of the most common LS-PIV based software programs
- Numerical approach to explore optimal experimental setup under different flow and tracer conditions
- Analysis of the influence of possible disturbances on the estimated surface velocity fields
- Identification of potential issues in the application to real cases
- Comparison between the two software performances, considering synthetic and real applications



Materials and Methods: LSPIV technique

LS-PIV enlarges the PIV (Particle Image Velocimetry) technique (Eulerian approach) to large-scale applications. It allows for estimating the surface velocity field staring from an image sequence of the liquid surface. Surface velocity is estimated indirectly by analysing the motion of a floating tracer (naturally present or artificially introduced).

Commercial digital cameras (e.g. small cameras; GoPro; smartphones, tablets; etc.).

Floater tracer with adequate geometry and density, uniformly distributed on a well-lit area of the region of interest.

SEEDING

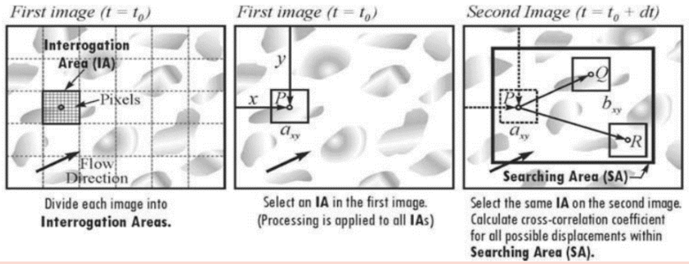
RECORDING

PROCESSING

Pre-processing | *Image Analysis* | *Post-processing*

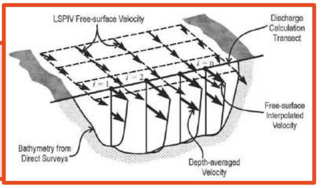
DISCHARGE EVALUATION

- **Pre-Processing:** orthorectification and graphic enhancement.
- **Image Analysis:** cross-correlation statistical analysis.



- **Post-Processing:** velocity field estimation (*filters, interpolation techniques; smoothing*)

Simplified assumptions about the vertical speed profile



Software characteristics

PIVLAB by ESRIG (NL)	FUDAA-LSPIV by DeltaCAD, EDF and Irstea (FR)
coded in MATLAB	coded in JAVA
INPUT	
Seq. type	
image sequences (.png, .jpeg, etc.)	image sequences (.png, .jpeg, etc.); video (.mp4, .avi, etc.)
Seq. processing style	
1-2; 2-3; 3-4; etc.; 1-2; 3-4; 5-6; etc.	1-2; 2-3; 3-4; etc.
PRE-PROCESSING	
image enhancement tools (CLAHE filter, highpass filter, auto contrast stretch, etc.)	image stabilization tool; orthorectification module (scaling, orthorectification with GCPs)
PIV ALGORITHM	
FFT-CC (up to 4 IAs); D-CC (IA and SA)	D-CC (IA and SA)
POST-PROCESSING	
vector validation tools, interpolation algorithm, mean velocity field, etc.	
OUTPUT	
2D representation of typical parameters (vectors, velocity magnitude, etc.)	

MODELING Framework

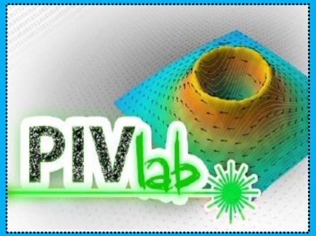
IMAGE SEQUENCE GENERATOR

Generation of synthetic image sequences (with fixed duration and frame-rate), simulating uniformly distributed tracers with constant concentration, moving under controlled conditions.

Sequences (100 replications) are generated under 4 different configurations with different **flow velocity** (**S**=slow or **F**=fast, according to a logarithmic cross-section profile) and **seeding density** (**LD**=low density, **HD**=high density)

IMAGE SEQUENCE PROCESSOR

PIVLab ***FUDAA-LSPIV***



All the synthetic and real sequences are processed by both the software, deriving the estimated velocity for the same region of interest (same computational grid)

FIELD SURVEYS

Two field campaigns with real video sequences acquisition at two different sections of the **Oreto** and **Pollina** rivers (Sicily- Italy). The tracer (woody chips) was artificially introduced and video were acquired through a commercial camera (with tripod) by an operator standing on a bridge

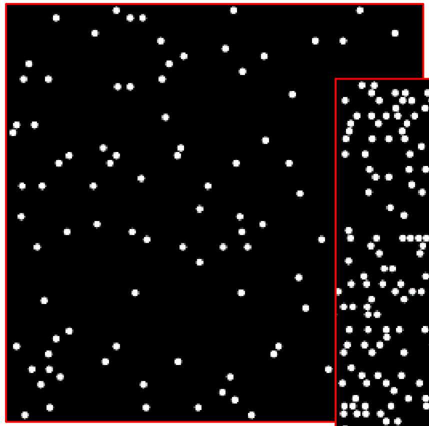
Materials and Methods: numerical simulations

IMAGE SEQUENCE GENERATOR SETTING					
CONSTANTS					
Frame dimension	600x600				*px*
Spatial resolution	0,003	*m/px*	Frame-rate	4	*fps*
Video duration	30	*s*	Frames per sequence	121	*fr*
Tracer	white disks		Background		black
Tracer diameter	10				*px*
VARIABLES					
Seeding density	low (LD)	0,02	*ppp*	≈ 90	*disks/fr*
	high (HD)	0,1	*ppp*	≈ 460	*disks/fr*
Mean flow velocity	slow (S)	0,5	*m/s*	≈ 42	*px/fr*
	fast (F)	1,5	*m/s*	≈ 125	*px/fr*

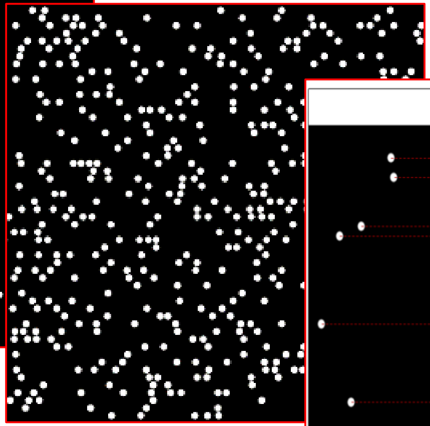
100 replications for each configuration

Tracer is randomly distributed with a uniform concentration, according to a Poisson distribution with parameter λ (density)

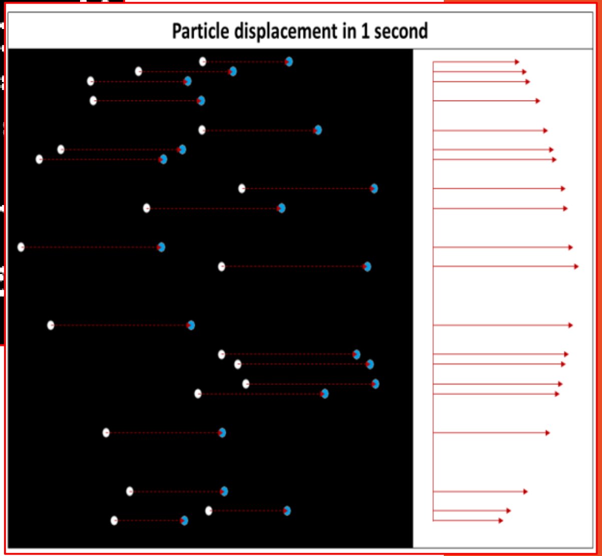
IMAGE SEQUENCE PROCESSOR SETTING					
PIVlab			**FUDAA-LSPIV**		
Grid	11x11	points	Grid	11x11	px
IA_1	400x400	px	IA	100x100	px
IA_2	200x200	px	$SA_{(SLOW)}$	120x120	px
IA_3	100x100	px	$SA_{(FAST)}$	360x120	px



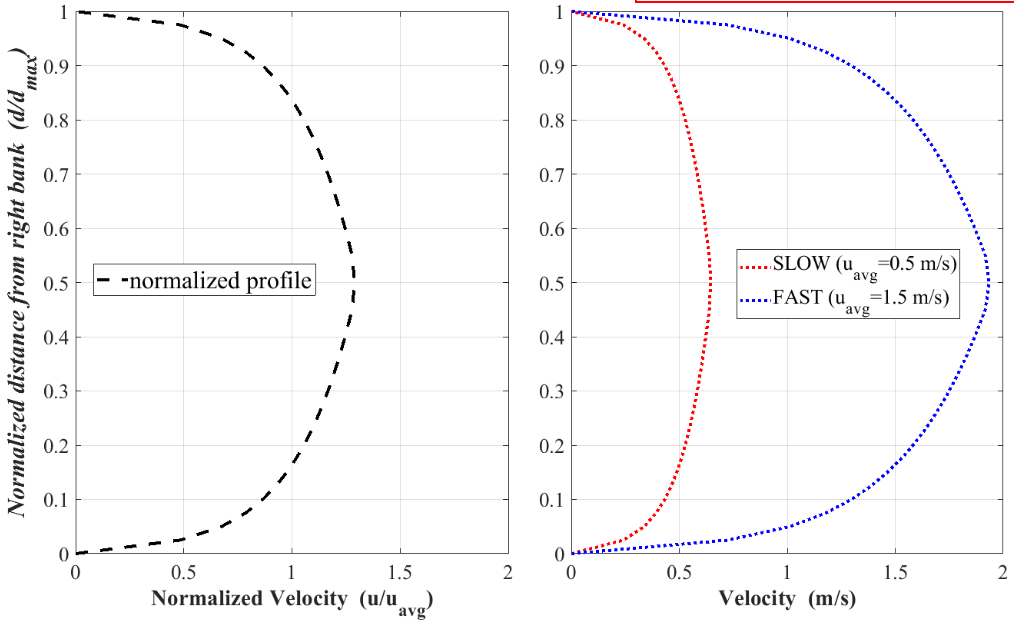
LD



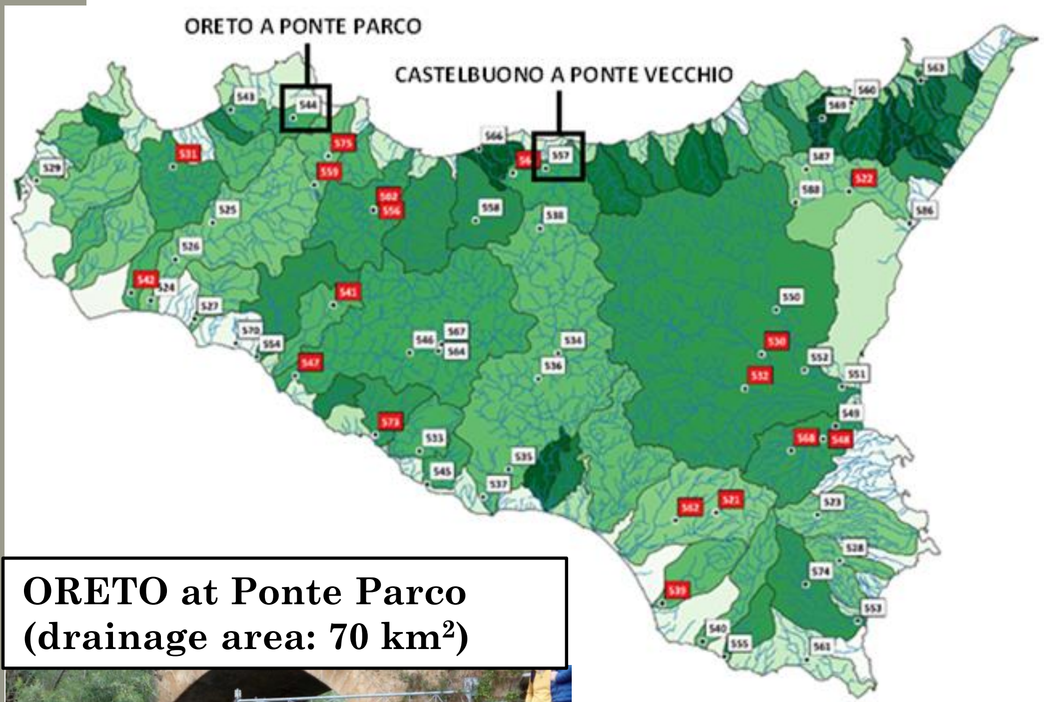
HD



Cross-section surface velocity profile

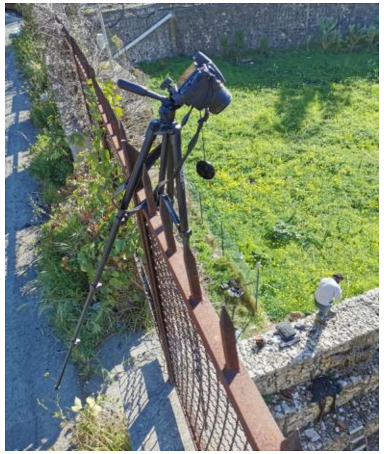


Materials and Methods: field surveys



ORETO at Ponte Parco (drainage area: 70 km^2)

POLLINA at Ponte Vecchio (drainage area: 100 km^2)



TRACER: natural woodchips

- density: 200-250 kg/m3
- heterogeneous shape and size;
- mean size: 3 cm.
- cost: 50 €/ton

CAMERA: Nikon Coolpix 530

- video resolution: 1080/16:9 1080/25p
- acquisition frame-rate: 25fps

Video-sequence		
Oreto		
Spat res	0,0172	m/px
Fr. rate	24	fps
Duration	30	s

Video-sequence		
Pollina		
Spat res	0,0208	m/px
Fr. rate	12	fps
Duration	30	s

SOFTWARE PARAMETERS		
PIVlab		
Grid	42x24	points
IA_1	64x64	px
IA_2	32x32	px
IA_3	16x16	px
FUDAA-LSPIV		
Grid	42x24	px
SA	64x64	px
IA	32x32	px

Results: numerical simulations

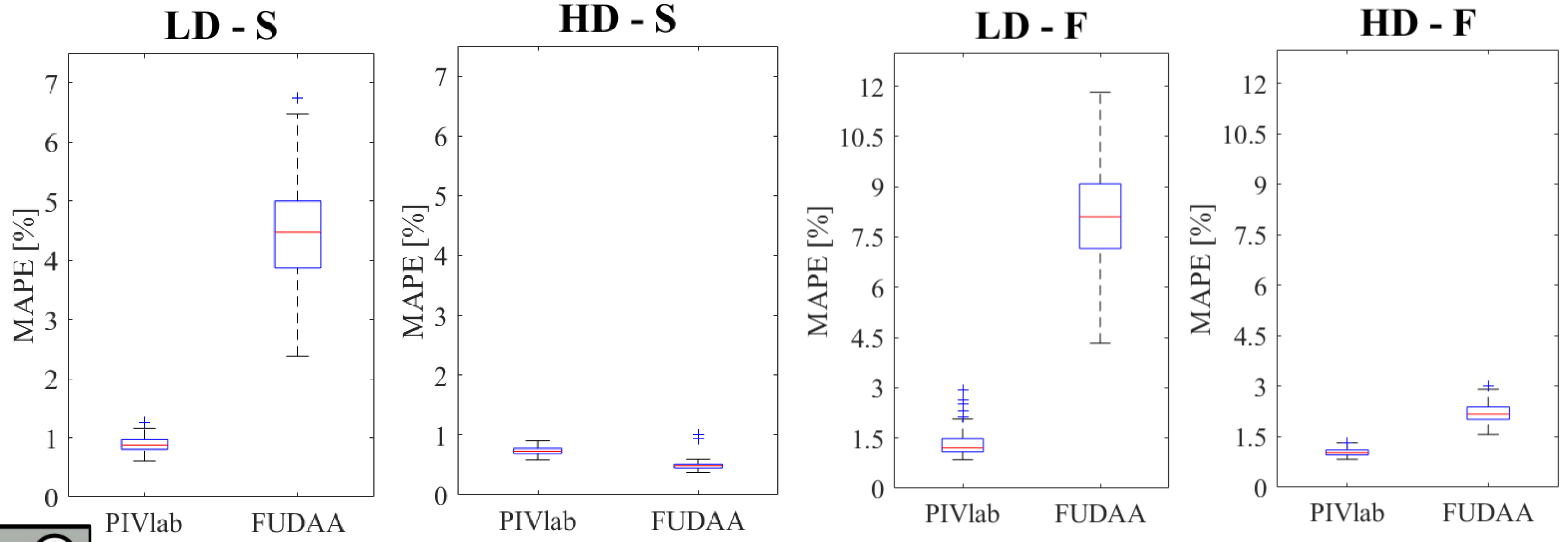
Estimation of the surface velocity field in a region of interest

Performance index: ***Mean Absolute Percentage Error*** (***MAPE***):

$$MAPE = \sum_{i=1}^{n} \left| \frac{v_{sim,i} - u_i}{u_i} \right| \%$$

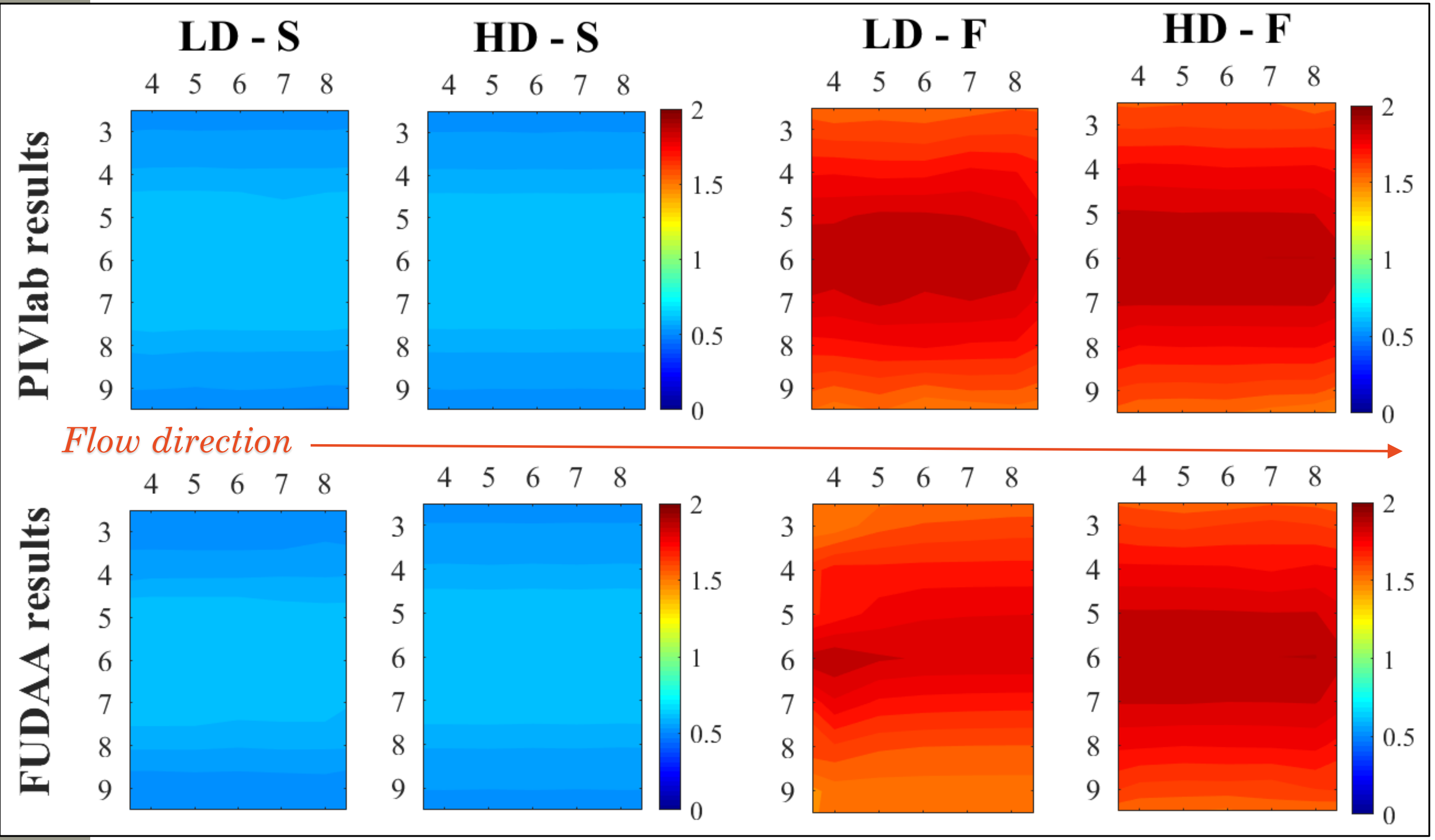
n= number of nodes of the computational grid;
$v_{sim,i}$= velocity estimated by software at the generic node i;
u_i= velocity imposed at the generic node i in the Image Sequence Generator;

- Performances for both the software increase for slower flow velocity (cases S)
- PIVLav performances are higher than FUDAA for the lower tracer density cases (LD-S and LD-F), while they are comparable for the higher density cases (HD-S and HD-F)

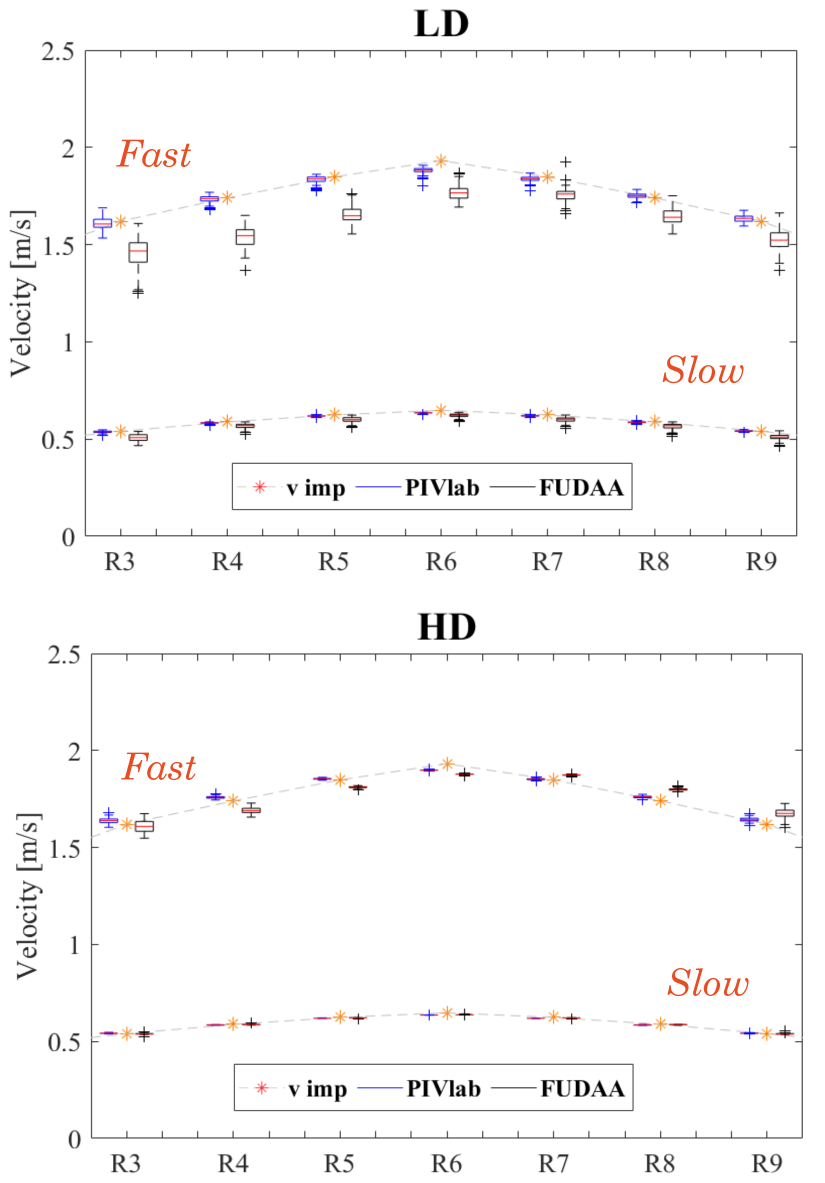


MAPE boxplot

Results: numerical simulations



Surface velocity field for the best case (lowest MAPE) of each configuration



Surface velocity profile at transect 6 for all the cases

Estimated velocity at each node is reported as boxplot of the values obtained for the 100 replications per configuration

- Lower uncertainty (lower IQR) can be associated to the PIVLab, especially for the slower flow velocity cases (S)

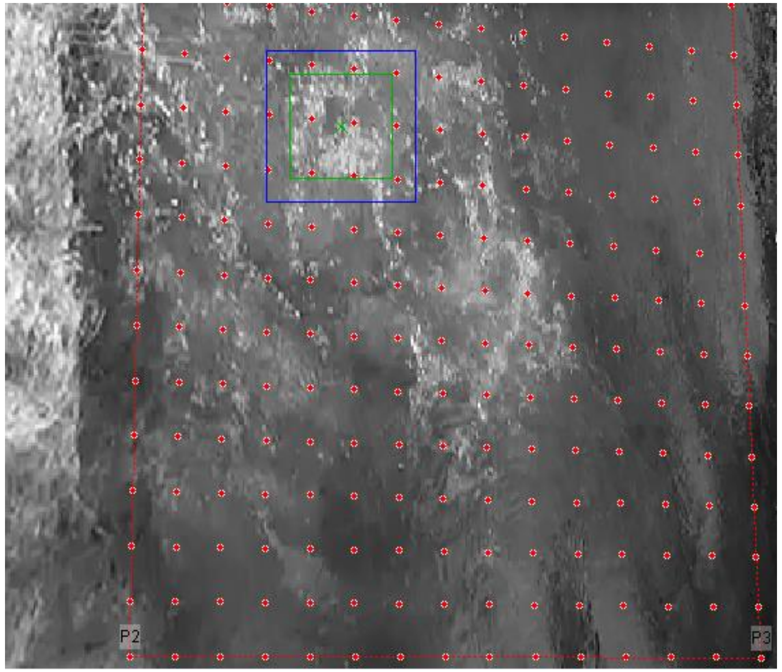
Results: field surveys

pre-processing

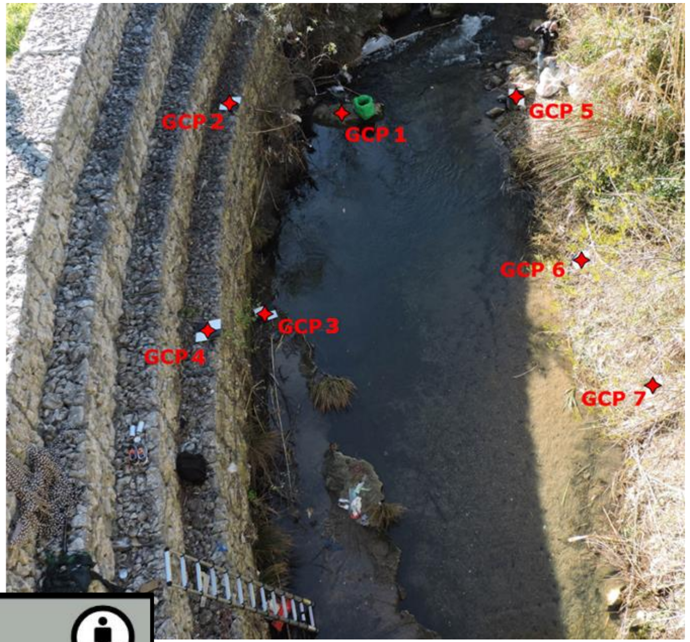
Video sequences have been preliminarily processed using the pre-processing module of FUDAA-LSPIV for:

- Orthorectification → selection of several GCPs (*Ground Control Points*) relieved by differential GPS;
- Stabilization → creation of a high-resolution (5 cm) DEM using an image acquired by drone and a commercial 3D modeling software (i.e., the *3DF Zephyr*)

The resulting sequences are then passed to the PIVLab and FUDAA for image analysis, using the same computational grid.

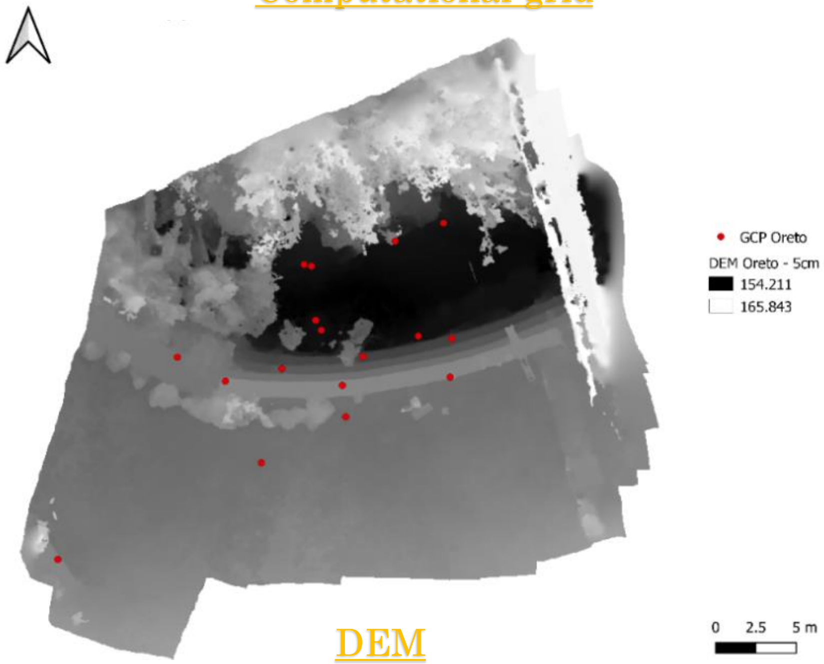


Computational grid



Oreto at Ponte Parco

Pollina at Ponte Vecchio



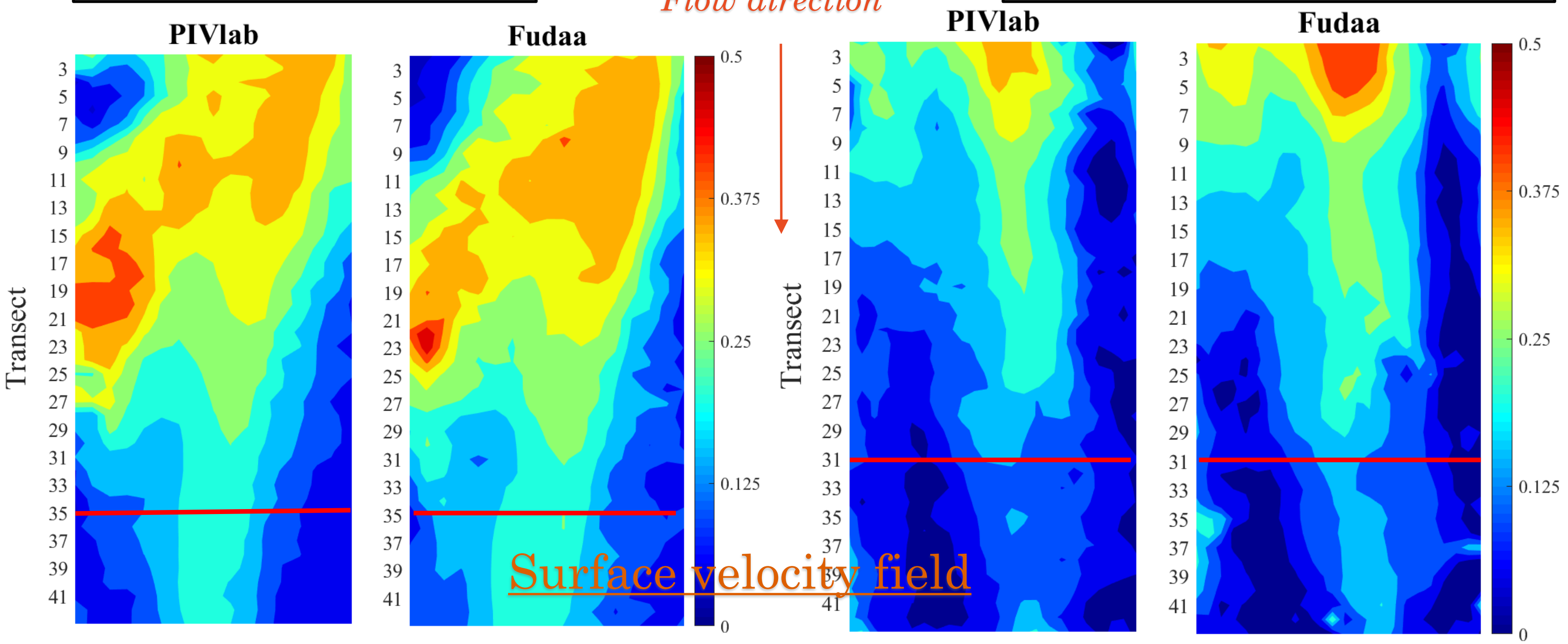
DEM

Results: field surveys

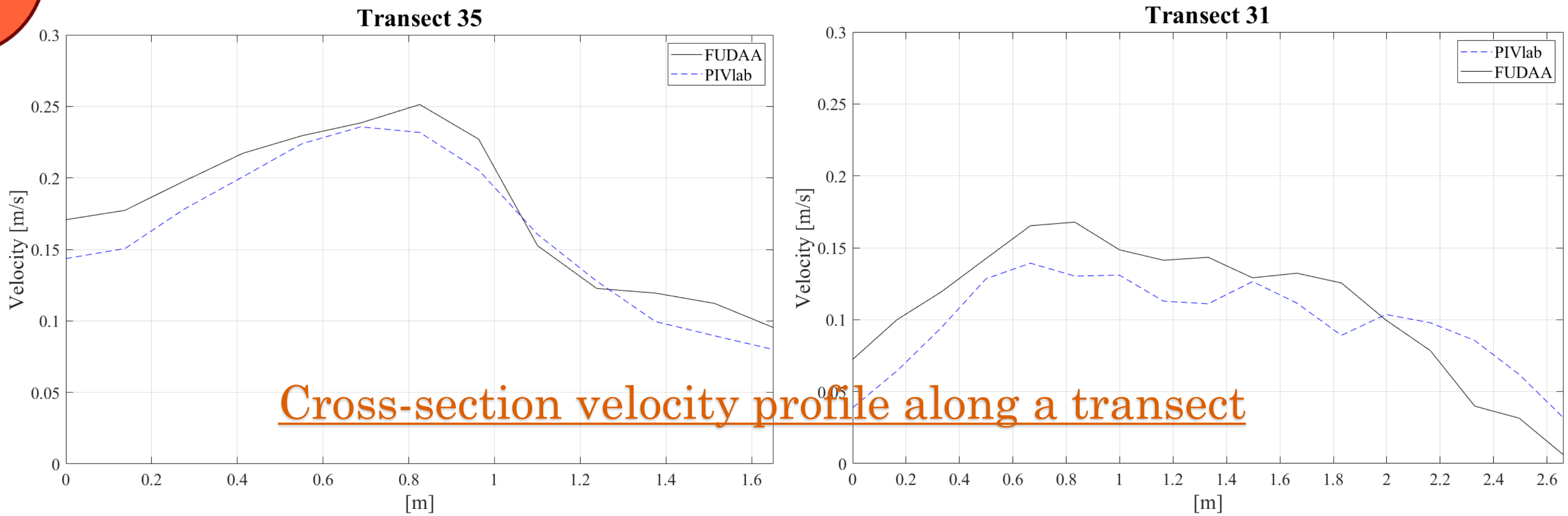
- The real cases can be equated with the synthetic HD-S cases.
- Velocity estimated by PIVLab is, on average, slightly higher than that estimated by FUDAA, especially for the Oreto case, reflecting some of the evidences from the numerical simulations.

ORETO at Ponte Parco

POLLINA at Ponte Vecchio



Surface velocity field



Cross-section velocity profile along a transect

Conclusions

Numerical approach could be seen of a sort of preparatory activity that could drive the experimental setup in real cases, providing useful suggestions for an appropriate parameterization in terms of tracer concentration depending on local flow conditions.

Particular important is the tracer concentration: a high concentration of particles ensures satisfying performance of LS-PIV matching algorithms for flow velocities lower than 1.5 m/s. The increase of tracer concentration reduces errors in velocity estimation and results uncertainty, even if, for the highest concentrations, individual particles could form clusters, with a consequent increase of the measuring uncertainties.

Both the investigated image processors resulted highly performing with regard to all the exanimated synthetic and real cases; PIVlab performances were slightly higher than FUDAA for synthetic cases with lower tracer density

Surface velocity fields and cross-section velocity profiles reconstructed for the two real cases by the two image processors resulted in strict agreement with each other, showing some of the potentialities of the LS-PIV technique

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