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LSPIV from the Rodeador Channel, using an UAV and a fixed camera to compare with an ADCP instrument of measure

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Abstract. *This work explores the LSPIV (Large scale particle image velocimetry) method as a tool to measure the surface velocity from open channels. The methodology derives originally from traditional PIV (Particle Image Velocimetry), which was studied in the early eighties to solve mechanics fluids problems. The analysis was made to estimate the surface velocity of the Rodeador Channel, the main agriculture channel from Brazlândia, a rural zone from Distrito Federal. The main objective is to propose a non-intrusive methodology to measure surface velocity at rivers and channels with reliable results. This work intends to verify the errors with and without applying a tracer to mark the flow. Also, check the differences on record through an UAV (unmanned aerial vehicle) and via a fixed camera.*

Keywords: *LSPIV, ADCP, Discharge, Drone, Flow*

1. INTRODUCTION

Measuring a river flow, it's not an easy task. Such an important factor of the hydrological characterization is necessary in many evaluations. As the amount of kinetic energy available, construction of bridges, highways and railroads and also to monitor the water balance in a water basin. Commonly approaches to measure flow, involves intrusive equipment, which implicate necessarily in higher risk to collect the data. Besides the risk involving the operator and also with the equipment, to perform such measurement the river needs to have an easy access. Ordinarily equipment use to this analysis are embrace by the technology of ADCP (Acoustic Doppler Current Profiler) that even through are really expensive they achieve a remarkable and reliable results.

The main idea of this work is to compare the already renowned ADCP methodology with the promising LSPIV (Large Scale Particle Velocimetry) methodology. The LSPIV method derives from the PIV (Particle Image Velocimetry) method, that was typically adopt to solve mechanics fluids problems in the early eighties. PIV found great acceptability of the scientific community for being a cheap and efficient method and at that time were expected that with technologies advances this method become even more efficient, cheaper and reliable (Fincham and Spedding, 1997). In 1983, a doctoral student, named Meynart was the leader in research related to this method and showed that measurements could be performed both in laminar flow as in turbulent flow of liquids. In his work he referred to technique like LSV (Laser Speckle Velocimetry), interestingly the images in their works they presented images of individual particles instead of spots (Adrian, 2005). Soon in 1984 researchers Pickering and Halliwel (1984) and Adrian (1984) came to the conclusion that the illumination of particles in fluid flows through a sheet of light would rarely create a pattern of spots in the image plane. Instead, the image plane would contain images of particles individual. To distinguish it from the LSV method, they named PIV.

The PIV system is basically made up of 4 elements: Flow visualization, lighting, video recording and image processing (Muste *et al.*, 2008). Developments in optics, laser, electronics and computer-related technologies facilitated the implementation and development of the technique. Soon the term PIV become frequent in laboratories studies of flow in the 90s (Adrian, 2005). The system basically works as a pattern matching technique, with a pre-processing phase and the image processing phase.

Fujita(1998) is the first author to use the name LSPIV (Large Scale Particle Image Velocimetry) for large scale PIV experiments. The first time this technique was applied to measure the velocity of a river was in Japan and as the studied area was larger than that traditionally area used for PIV experiments, the name LSPIV become more adequate (AYA *et al.*, 1995). It could be experiments in hydraulic laboratories, rivers, channels or floods events. Measuring the surface velocity of a water course is a very important factor in the hydrological characterization. New methods that can help in the hydrological characterization is totally necessary, mostly in a country like Brazil. The benefits of this method if compares to usual ones, like bathymetry, sonar and ADCP (Acoustic Doppler Current Profiler) is that LSPIV is a non-intrusive instrument, so it does not need to be in contact with the fluids. Ensuring more safety for the operator of the system and possibility to records measurements in extreme events, without the risk of losing or breaking the equipment during measurement.

LSPIV generally uses natural sunlight or an artificial source of light to illuminate the flow and usually the camera installed to record the movement is not perpendicular to the fluid, therefore, it is necessary to introduce an orthorectification process that requires in the registered image field ground control points (GCP).

The experiment in this work consists in two cameras recording the Rodeador channel. One fixed camera,Gopro, and a camera in a Drone,DJI Phantom 4, flying above the channel. It was added to the river channel sawdust to work as a natural tracer, so it could compare the different results obtain with sawdust and without. The videos were process in an open software call RIVeR (Patalano *et al.*, 2017) and PIVLAB (Thielicke and Stamhuis, 2014). For a reasonable record its necessary to mark at least 4 GCP that can be identify on the record. It's also imports to guarantee a good natural illumination. The gopro and drone were recording simultaneously and the floodgate was completely close at the begin of the experiment. The first record happens after the floodgate had been opened 2,5 *cm* and the water level stabilize. Then after the first record it was use an ADCP equipment, FlowTracker, to measure the velocity in a define section of the channel and the flow. For both of the other videos the same procedure was performed. Open 2,5 *cm* the floodgates, wait for the water level to stabilize and then start recording the videos and perform the measurement with the FlowTracker.

2. Methodology

The methodology of this work is divide in two phases. The pre-processing phase, where it will be explained, how the images were obtain from the field and how the FlowTracker works and how was operate. The second phase is the image processing phase. With the support of the software RIVeR (Patalano *et al.*, 2017) to orthorectify the images and the PIVLab (Thielicke and Stamhuis, 2014) to process the frames from the videos orthorectified was possible to estimate the surface velocity from the Rodeador Channel.

2.1 Pre-Processing:

The irrigation channel, named Rodeador channel, where the experiment occurred, was made between 1966 and 1973, which is located in the administrative region of Brazlândia, a rural zone from Federal District (ADASA, 2018). It's the largest irrigation channel in Federal District, there are 18*km* of main channel and 25 *km* if counting the ramifications. It serves approximately 102 farms of rural producers, who mostly produce vegetables in the form of subsistence agronomy. The channel was created by barring the Rodeador stream, which is the main tributary of the Descoberto Lake, and through a floodgate, see figure 1(a), regulated by ADASA (Water, Energy and Basic Sanitation Regulatory Agency of the Federal District), the flow pass to the channel, see figure 1(b) and 1(d).

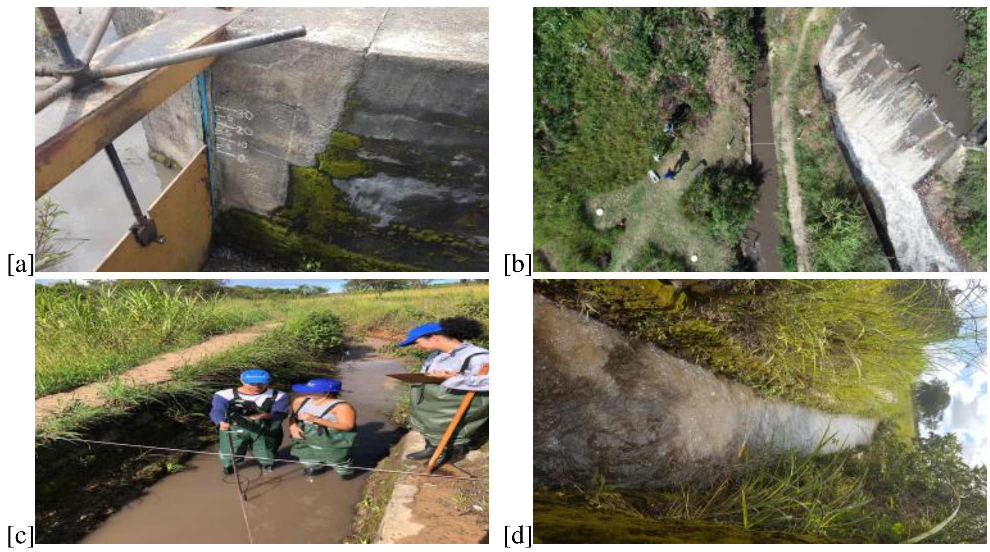


Figure 1. Views from Rodeador Channel.

The endowment, given by ADASA, from the channel is seasonal and every month an inspection team, see figure 1 (c) measures the discharge using an ADCP (Acoustic Doppler Current Profiler) equipment, FlowTracker. It measures velocities with a range as low as 0.001 *m/s* and up to 4.5 *m/s*, when combined with a measuring tape, the FlowTracker can operate to measure the total discharge across a river or channel section (SonTek, 2011). Follows basically the same principle of measuring discharge than a hydrometric reel and have various ways of calculating it. In this work the discharge was calculate using the method of one point. Consist in a measure that in different points of a cross section from a river, on each measure location where the equipment will operate, be at 60% of the total depth of that specific measuring point, see figure 2

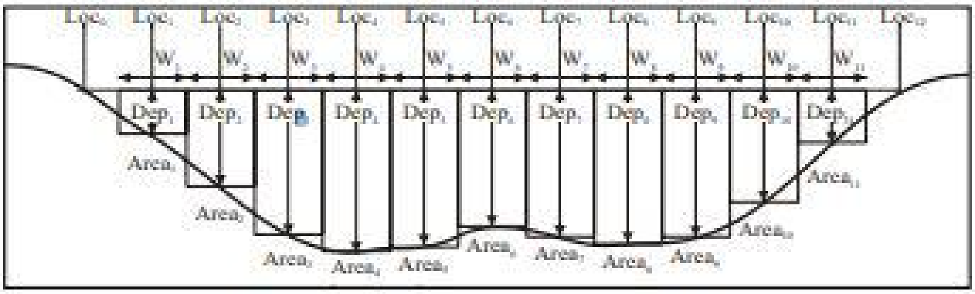


Figure 2. FlowTracker discharge calculation method(SonTek, 2011)

In each measure the equipment asks to inform the actual location and the depth of the specific point and then calculate the velocity of each point. With the area and the velocity for each section, the equipment calculates the discharge from each section, see equation 1 and then the total discharge of the channel, see equation 2.

$$q_i = (V_i)(A_i) \tag{1}$$

$$\mathbf{Q} = \sum_{k=i}^{n} q_i \tag{2}$$

Using a measuring tape the channel was measured and the length of the cross section where the FlowTracker operated was of 1.35 *m*. Using a chalk, six GCP were marked on the field and the Gopro camera was installed on a tripod to avoid shaking, see figure 3[a]. The Drone used to record the flow was a DJI Phantom 4, see figure 3[b]. The gopro wasn't perpendicular to the flow and the Drone was at a higher approximately of 8 meters high, enough to the drone's wind don't disturb the water flow.

[a]  [b] 

Figure 3. Views from Rodeador Channel.

The natural tracer add to the channel was sawdust, is biodegradable and won't cause any problem in the water quality. Both cameras started to record simultaneously and the first video filmed was adding the sawdust, then after all the sawdust had gone with the flow another video were filmed simultaneously by both cameras without the sawdust. After both of the video were taped, the measurement with the FlowTracker equipment began. This whole process happened twice. One with the floodgates openness of 2.5 *cm* and then with an openness of 5 *cm*. The pre-processing phase finished with a total of 8 videos recorded and 2 FlowTackers analysis.

2.2 Image processing:

After collecting the images on the field, the next step is process them. First it needs to extract the frames from the videos. Using the PIVlab software (Thielicke and Stamhuis, 2014) the frames for each video were extracted and the time between each frame was determined. The gopro videos were record at 60 fps and the extraction obtain a time between the frames of 16.68 ms and a total of 300 frames extract. The Drone videos were record at 30 fps and the extraction obtain a time between each frame of 33.36 ms and a total of 150 frames extract. Proceeding with the processing, now that the frames were extracted it has to be orthorectified. Using the GCP added to the field with a chalk and with the RIVeR program (Patalano *et al.*, 2017) all the frames extracted were orthorectified, see figure 4-a and 4-b.

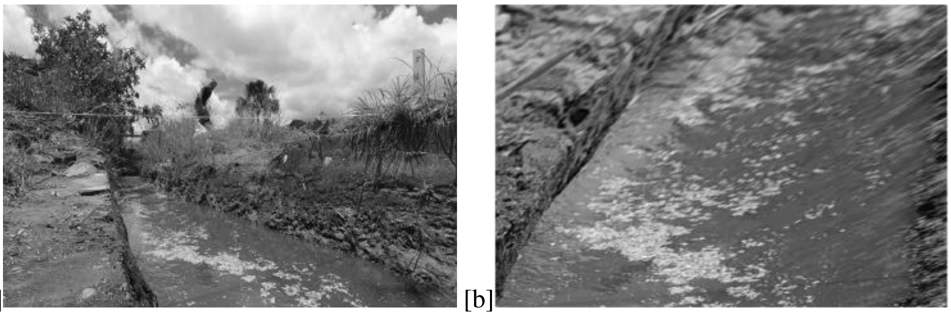
[a] [b]


Figure 4. Image from fixed camera

Now with all the frames orthorectified, the next step is use the PIVLab software (Thielicke and Stamhuis, 2014) to the particle image analyze began. The technique basically consist of an image matching pattern. Each pair of frames will be analyze together. The program works defining a region of interest (ROI) in the first frame of the pair. In this ROI is define some searching areas (SA), grid box that decreases in size proportionally. The idea is to characterize the pixel inside these boxes, calling this characterize pixel of interrogation point, and search for this same pattern in the next frame of the image pair. This characterization and search for pattern is the most sensitive part of the LSPIV. This analyze is made by a cross correlation algorithm. In essence, the cross-correlation is a statistical pattern matching technique that tries to find the particle pattern from interrogation area A back in interrogation area B (Thielicke and Stamhuis, 2014). This statistical technique is implemented with the discrete cross correlation function, see equation 3:

$$\mathbf{C}_{m,n} = \sum_{k=i}^{n}\sum_{k=j}^{n} A(i,j)B((i-m,j-n) \tag{3}$$

Where A and B are corresponding interrogation areas from frame A and frame B. There are two common approaches to solve equation 3. The most straightforward approaches is to compute the correlation matrix in the spatial domain, this approach is called direct cross correlation. The other approach is to compute the correlation matrix in the frequency domain, and is called Discrete Fourier Transformation (DFT). Both approach are available at PIVLab, and both have their advantages and disadvantages. For this work the discrete Fourier transformation was used because it demand a lower computational cost to solve the cross correlation. After defining the ROI and the SA in the first pair of frame, we expand the selection to all the frames extract from the videos and through DFT the surface velocity vectors of the channel are obtained. This processing was performed for each video record at the Rodeador Channel. So in total there were eight processed videos. Four with the sawdust and four without. The velocity vector from the Gopro camera and the Drone can be seen in the figure 5(a) and 5(b) respectively.

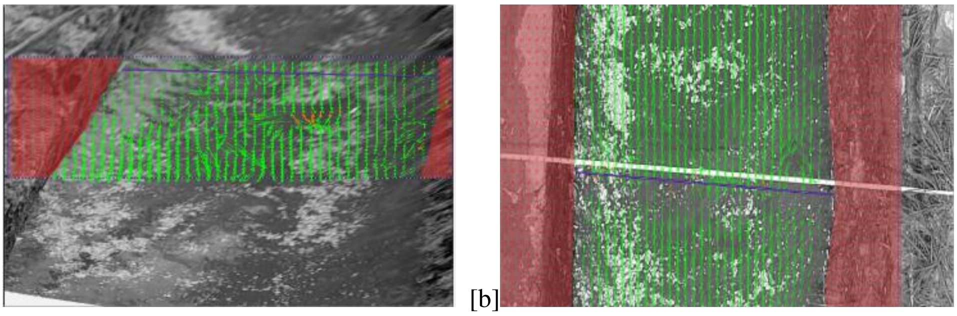
[a] [b]


Figure 5. Velocity vector field

3. Results:

In this section we present the results obtained from PIVLab program and from the FlowTracker device. The analyze from the PIVlab resulted in a vector field of superficial velocity, inside the ROI. To compare with the results from the FlowTracker, it was extracted from the vector field the velocity only from the same cross section that the FlowTracker operate. The result that the FlowTracker device provides are shown in the figures 6 and figure 7. Important to mention that the total area in the analyses from the ADCP device change because the floodgates opened 2,5 cm more from one measure to the other. For better understanding and comparison of the measurements from the FlowTracker and LSPIV analyze, the measurements will be named measurements 1, see Figure 6, and measurement 2, see Figure 7.

The register velocity from the FlowTracker was plot with LSPIV analyze through the length of the channel. So, it would be possible to analyze the trend of the velocity on the channel between equipment. The figure 8 compares the first

Discharge Measurement Summary — Date Generated: Thu Mar 5 2020

File Information	
File Name	ROD3.PC.WAD
Start Date and Time	2020/03/03 10:45:06

Site Details	
Site Name	03032020
Operator(s)	EDU

System Information	
Sensor Type	FlowTracker
Serial #	P2560
CPU Firmware Version	3.5
Software Ver	2.30
Mounting Correction	0.0%

Units	(Metric Units)
Distance	m
Velocity	m/s
Area	m^2
Discharge	m^3/s

Discharge Uncertainty		
Category	ISO	Stats
Accuracy	1.0%	1.0%
Depth	0.5%	1.6%
Velocity	1.0%	6.2%
Width	0.2%	0.2%
Method	2.7%	-
# Stations	4.6%	-
Overall	**5.6%**	**6.5%**

Summary			
Averaging Int.	30	# Stations	11
Start Edge	LEW	Total Width	1.350
Mean SNR	40.3 dB	Total Area	0.294
Mean Temp	21.79 °C	Mean Depth	0.218
Disch. Equation	Mid-Section	Mean Velocity	0.2739
		Total Discharge	**0.0805**

Measurement Results

St	Clock	Loc	Method	Depth	%Dep	MeasD	Vel	CorrFact	MeanV	Area	Flow	%Q
0	10:45	2.20	None	0.000	0.0	0.0	0.0000	1.00	0.0000	0.000	0.0000	0.0
1	*10:45*	*2.10*	*0.6*	*0.180*	*0.6*	*0.072*	*0.0178*	*1.00*	*0.0178*	*0.023*	*0.0004*	*0.5*
2	10:50	1.95	0.6	0.180	0.6	0.072	0.2924	1.00	0.2924	0.027	0.0079	9.8
3	10:52	1.80	0.6	0.180	0.6	0.072	0.2687	1.00	0.2687	0.027	0.0073	9.0
4	10:53	1.65	0.6	0.190	0.6	0.076	0.3205	1.00	0.3205	0.029	0.0091	11.3
5	10:56	1.50	0.6	0.240	0.6	0.096	0.3002	1.00	0.3002	0.036	0.0108	13.4
6	10:58	1.35	0.6	0.290	0.6	0.116	0.2882	1.00	0.2882	0.044	0.0125	15.6
7	11:00	1.20	0.6	0.300	0.6	0.120	0.2748	1.00	0.2748	0.045	0.0124	15.4
8	11:01	1.05	0.6	0.300	0.6	0.120	0.2863	1.00	0.2863	0.038	0.0107	13.3
9	11:03	0.95	0.6	0.270	0.6	0.108	0.3480	1.00	0.3480	0.027	0.0094	11.7
10	11:03	0.85	None	0.000	0.0	0.0	0.0000	1.00	0.0000	0.000	0.0000	0.0

Rows in italics indicate a QC warning. See the Quality Control page of this report for more information.

Figure 6. Summary from FlowTracker measurement 1(SonTek, 2011)

Discharge Measurement Summary — Date Generated: Thu Mar 5 2020

File Information	
File Name	ROD4.PC.WAD
Start Date and Time	2020/03/03 11:34:45

Site Details	
Site Name	03032020
Operator(s)	EDU

System Information	
Sensor Type	FlowTracker
Serial #	P2560
CPU Firmware Version	3.5
Software Ver	2.30
Mounting Correction	0.0%

Units	(Metric Units)
Distance	m
Velocity	m/s
Area	m^2
Discharge	m^3/s

Discharge Uncertainty		
Category	ISO	Stats
Accuracy	1.0%	1.0%
Depth	0.3%	2.2%
Velocity	1.2%	6.1%
Width	0.2%	0.2%
Method	2.7%	-
# Stations	4.6%	-
Overall	**5.6%**	**6.6%**

Summary			
Averaging Int.	30	# Stations	11
Start Edge	LEW	Total Width	1.350
Mean SNR	46.1 dB	Total Area	0.398
Mean Temp	21.96 °C	Mean Depth	0.294
Disch. Equation	Mid-Section	Mean Velocity	0.3278
		Total Discharge	**0.1303**

Measurement Results

St	Clock	Loc	Method	Depth	%Dep	MeasD	Vel	CorrFact	MeanV	Area	Flow	%Q
0	11:34	2.20	None	0.000	0.0	0.0	0.0000	1.00	0.0000	0.000	0.0000	0.0
1	11:35	2.10	0.6	0.240	0.6	0.096	0.0010	1.00	0.0010	0.030	0.0000	0.0
2	11:38	1.95	0.6	0.260	0.6	0.104	0.3756	1.00	0.3756	0.039	0.0146	11.2
3	11:40	1.80	0.6	0.270	0.6	0.108	0.3862	1.00	0.3862	0.041	0.0156	12.0
4	11:42	1.65	0.6	0.300	0.6	0.120	0.3556	1.00	0.3556	0.045	0.0160	12.3
5	11:45	1.50	0.6	0.360	0.6	0.144	0.3084	1.00	0.3084	0.054	0.0167	12.8
6	11:47	1.35	0.6	0.380	0.6	0.152	0.3110	1.00	0.3110	0.057	0.0177	13.6
7	11:49	1.20	0.6	0.400	0.6	0.160	0.3270	1.00	0.3270	0.060	0.0196	15.1
8	11:52	1.05	0.6	0.320	0.6	0.128	0.4119	1.00	0.4119	0.040	0.0165	12.6
9	11:53	0.95	0.6	0.320	0.6	0.128	0.4214	1.00	0.4214	0.032	0.0135	10.4
10	11:53	0.85	None	0.000	0.0	0.0	0.0000	1.00	0.0000	0.000	0.0000	0.0

Rows in italics indicate a QC warning. See the Quality Control page of this report for more information.

Figure 7. Summary from FlowTracker measurement 2(SonTek, 2011)

measurement from each camera with the results from the FlowTracker. The Figure 8(A) shows the velocity through a define section from the channel from the images obtain with Drone and with the sawdust added to the flow. The Figure 8(B), 8(C) and 8(D) shows the same analyze but without sawdust, with different camera and different camera and without sawdust respectively.The Figure 9 is overlapping all this results so it can be clear to compare which equipment got closer to the ADCP device.The same logistics was apply to figure 10 (A),(B),(C) and (D). Also figure 11 overlaps all the equipment for a better comparison.

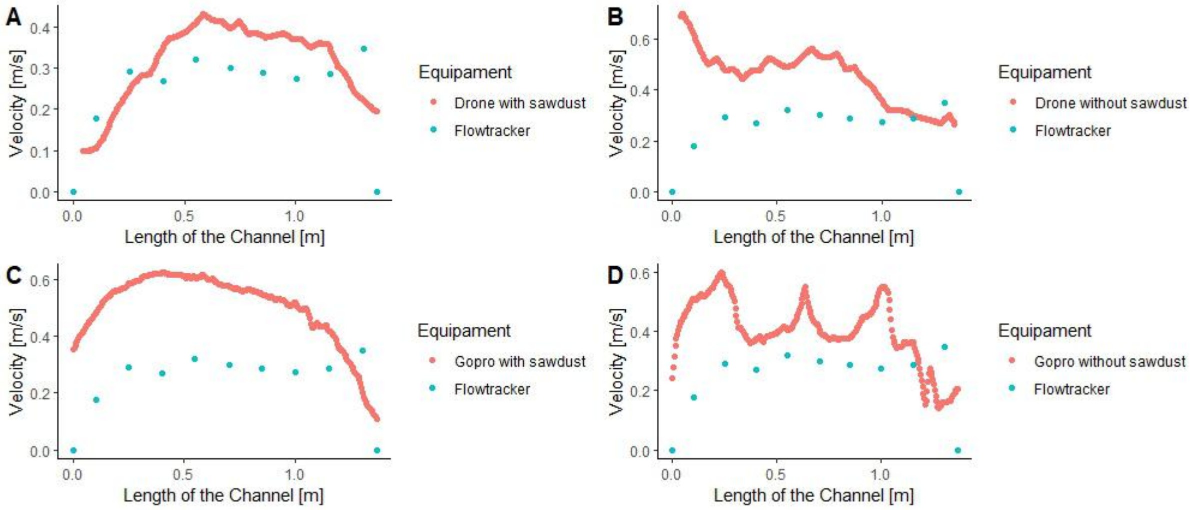


Figure 8. Velocity through the cross section of the Rodeador Channel from the Measurement 1

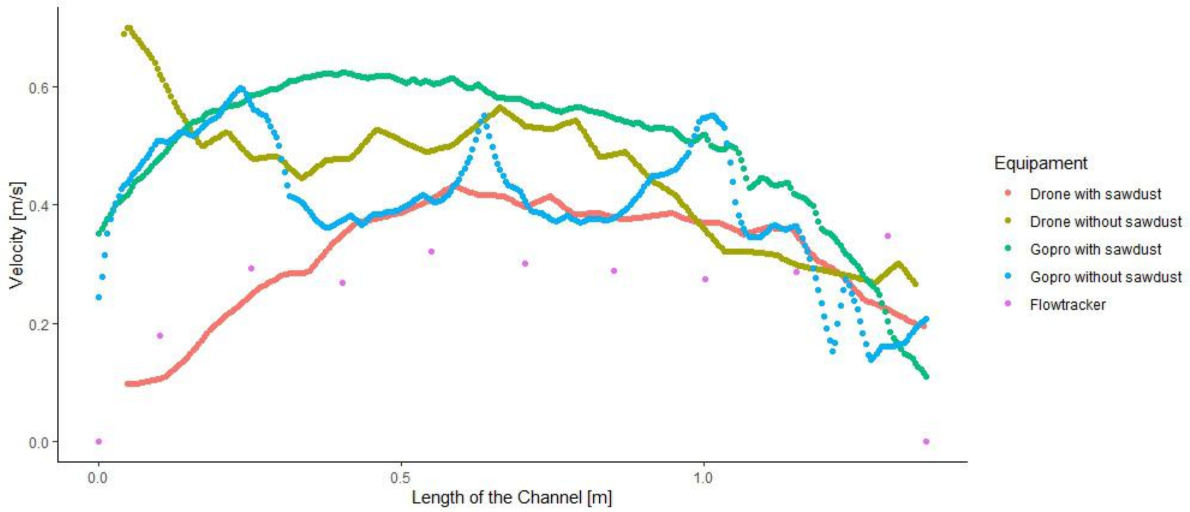


Figure 9. Overlapping results from measurement 1

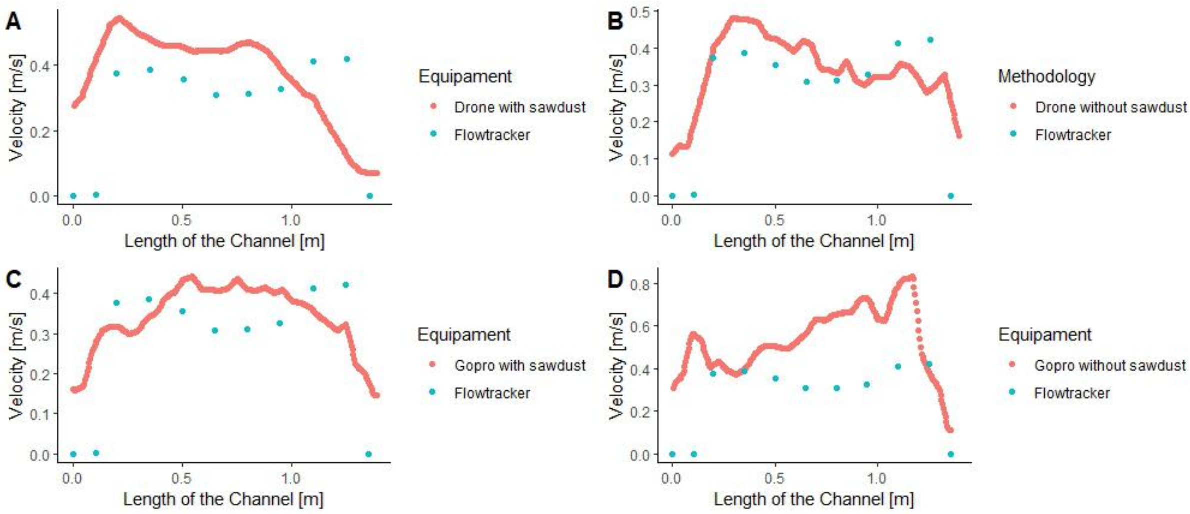


Figure 10. Velocity through the cross section of the Rodeador Channel from the Measurement 2

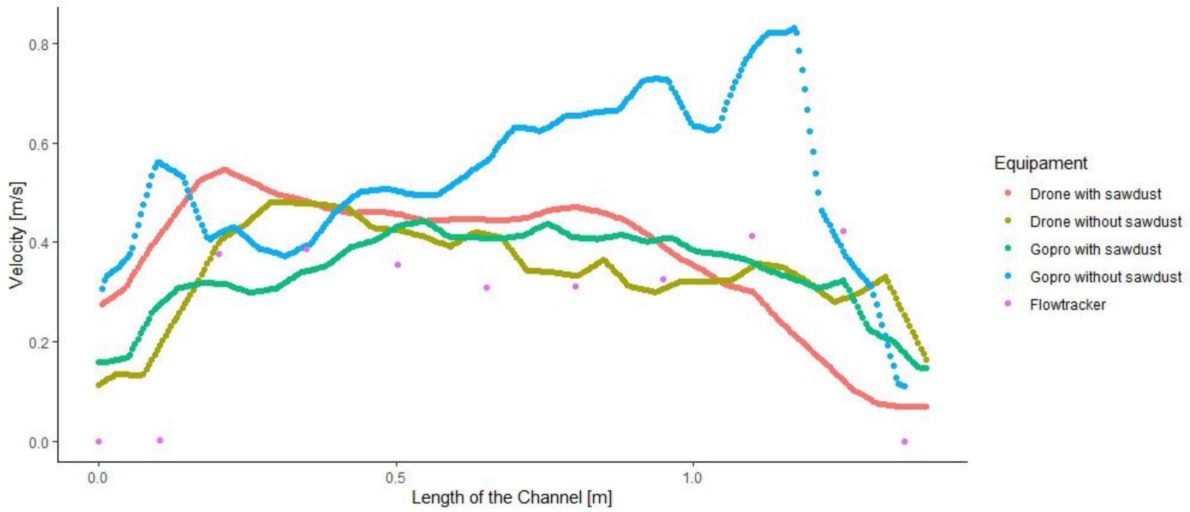


Figure 11. Overlapping results from measurement 2

Both analyze demonstrate that the behavior from the velocity is to be smaller at the margins and larger at the center of the channel, as expected. Now to compare these results with the discharge some information about the calculation most be inform. The FlowTracker use the method of one point, that is to use the Velocity at 60% of the total depth of that point to be the mean velocity of that location to calculate the discharge of that area. In the LSPIV method was obtained the mean superficial velocity at each point through the channel. So, in order to use this velocity to calculate the discharge it was necessary to multiplied this value by a correction factor of 0.85. Then the discharge was calculate being equal to the area of the cross section multiplied by the mean velocity of the section with this correction factor already applied. Outcoming the figure 12 and figure 13, from the measurements 1 and 2 respectively.

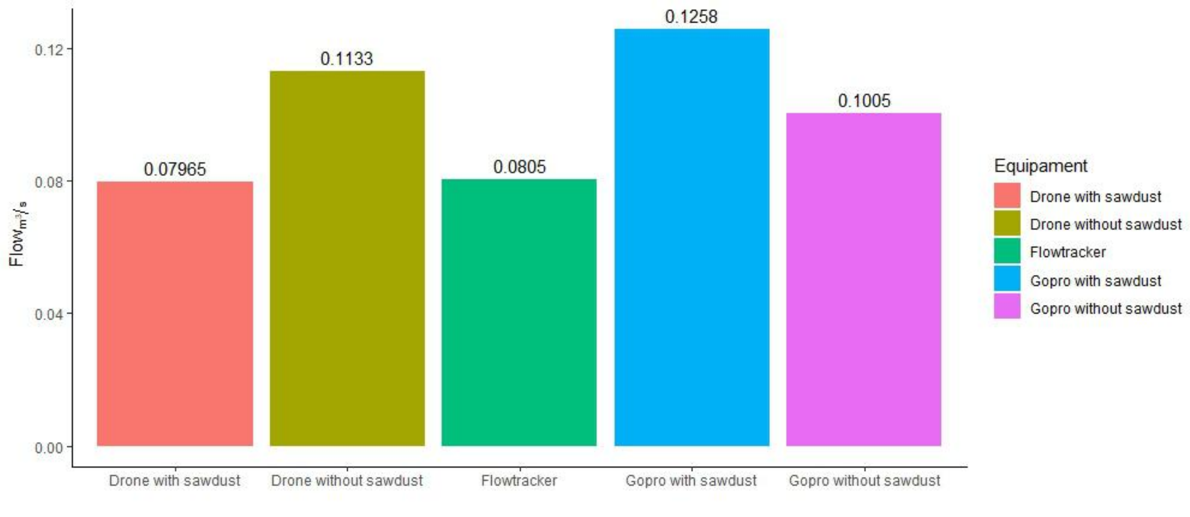


Figure 12. Discharge comparison from measurement 1

4. Conclusion:

The results obtained were satisfactory. It is possible to perceive from the figure 12 and figure 13 that the analyze with the Drone and with sawdust secure the best results comparing to the FlowTracker. Adding a natural tracer improve the LSPIV method, even that the Gopro with sawdust from measurement 1 had some bad results comparing to the other. Comparing the results between the fixed camera and the drone camera, the drone camera obtains better results. Probably because the position where the Gopro camera was fixed obtain images with a lot of shadows from the channels wall.

To conclude the LSPIV method is cheaper, faster and a non-intrusive method compared to the FlowTracker method. A typical measurement with the ADCP device takes at least 15 to 20 *minutes* in this small section of channel, as the LSPIV method the camera recorded only 30 *seconds* of the flow and was enough to accomplish the measurement. To guarantee the reliability of the method is important to insure a good illumination of the flow and a good camera stabilization. The

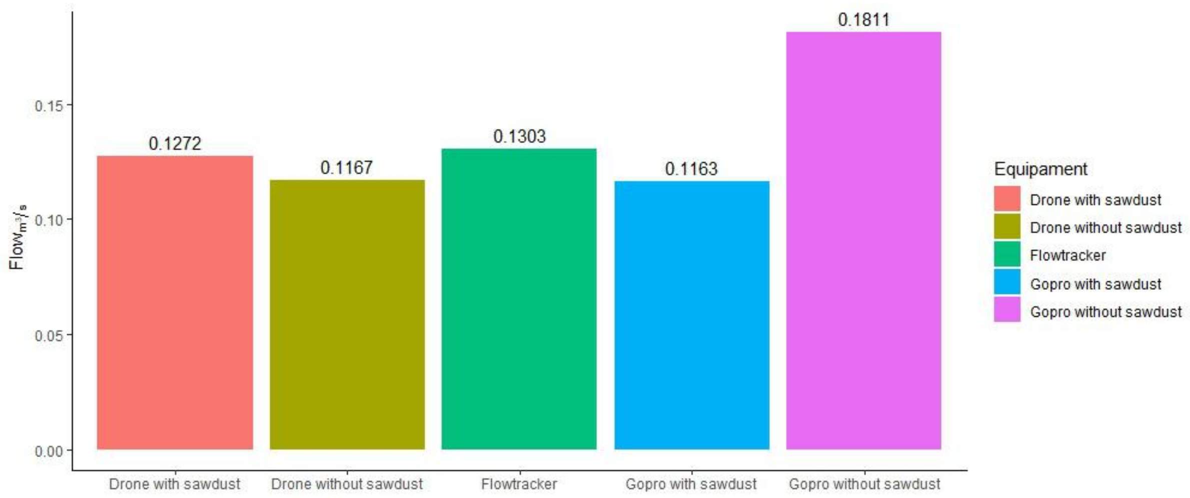


Figure 13. Discharge comparison from measurement 2

possibility of measuring discharges with a Drone is remarkable because it can be applied to river that does not have safety or easy access and the LSPIV can also be applied to flood events or extreme situations like leakage of dams to measure the velocity of spread, also the possibility of installing a fixed camera provides a simple control of the flow and can generate information daily about your flow.

5. ACKNOWLEDGEMENTS

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7. RESPONSIBILITY NOTICE

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