Particle Image Velocimetry for Measuring Water Flow Velocity

King Kuok Kuok, Po Chan Chiu

***Abstract*—**Floods are natural phenomena, which may turn into disasters causing widespread damage, health problems and even deaths. Nowadays, floods had become more serious and more frequent due to climatic changes. During flooding, discharge measurement still can be taken by standing on the bridge across the river using portable measurement instrument. However, it is too dangerous to get near to the river especially during high flood. Therefore, this study employs Particle Image Velocimetry (PIV) as a tool to measure the surface flow velocity. PIV is a image processing technique to track the movement of water from one point to another. The PIV codes are developed using Matlab. In this study, 18 ping pong balls were scattered over the surface of the drain and images were taken with a digital SLR camera. The images obtained were analyzed using the PIV code. Results show that PIV is able to produce the flow velocity through analyzing the series of images captured.

***Keywords*—**Particle Image Velocimetry, flow velocity, surface flow.

I. Introduction

FLOODS are natural phenomena, which have helped to shape natural landscapes, habitats and ecosystems in floodplains, wetlands, lowlands etc. However, floods may turn into disasters causing widespread damage, health problems and even deaths. These especially happened when rivers have been cut off from their natural floodplains, and confined to man-made channels, where houses and industrial sites have been constructed in areas that are naturally liable to flooding. Nowadays, floods had become more serious and more frequent due to climatic changes.

Flooding can be caused by a variety of weather and related phenomena, including tropical cyclones, low pressure systems, thunderstorms, snowmelt, and debris flows. There are various types of flooding include tidal flooding, fluvial Flooding, flash flooding, ground water levels rise, pluvial flooding, flooding from sewers, flooding from man-made infrastructure etc. Floods are impossible to be totally prevented, but flood frequency and damages can be reduced through flood mitigation measures.

The flow rate of floods are normally measured in cubic meter per second (m^3/s), cubic feet per second (cfs) or gallons per minute (gpm). The flow rate is a product of flow velocity and the river cross section. According to United States Geological Survey (USGS), there are a few methods to measure stream flows including mechanical velocity meter, current meter, acoustic doppler velocimeter, acoustic doppler current profiler, portable flumes, parshall flume, volumetric measurement, floatation etc. All these methods required the hydrographer get near or contact with the water bodies.

During flooding, discharge measurement still can be taken by standing on the bridge across the river using portable measurement instrument. However, it is too dangerous to get near to the river especially during high flood. In such situation, hydrologists and hydrographers will engage the land surveyor to check the level of rising flood water by reading the stickgauge using theodolite. This gauging method is not applicable if the stickgauge are not installed on site.

Therefore, this study employs Particle Image Velocimetry (PIV) as a tool to measure the surface flow velocity.PIV is a 'digital' tracking process to calculate the length of time for which water has been moved from one point to another [1]. The selected study area is a 5m length perimeter drain with a dimension of 250mmX250mm. The aim of this study is to develop the MatPIV code written in Matlab for analyzing the captured photographs and create an accurate model of the surface flow profile.

II. Particle Image Velocimetry (PIV)

PIV is a non-intrusive velocity field mapping technique that makes use of captured optical images to produce instantaneous vector measurements [2]. The basic concept of PIV is utilizing statistical evaluation of PIV images for determining the displacement between particles. Movement of particles through a target ('interrogation') area in a set time frame is measured to calculate the velocity profiles [3].

In the case of a high speed water flow, laser will be used to pulse on and off twice for illuminating tracer particles within the flow. It is assumed that the tracer particles move with the local flow velocity between the two illuminations, and give an accurate representation of actual flow. The light scattered by the tracers on the first pulse will be captured to produce the first image. A subsequent image will then be produced with the second laser pulse. It is the movement of particles between these two images that is used to calculate the velocity vectors for the flow.

Meanwhile, in the case of a slow flowing pond, a standard digital camera is programmed to take sequential images at set time intervals using background lighting. The shutter in the camera acts like the pulsing laser and will allow for two

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sequential exposures. In order to attain high quality image, it is important to ensure that there is a distinct contrast between the seeded particles and the flowing fluid. It is also need to ensure that an interrogation area is not saturated with particles or conversely particle deficient.

The quality of the images is crucial in PIV as poor images will produce poor data. Therefore, it is essential to remove noise in the data using post-processing technique to the images and only analyze valid velocity vectors.

PIV used Fast Fourier Transform (FFT) cross correlation to digitally examine and track the flow from two digital images. The equations of correlation using Fast Fourier Transforms are presented in Fig. 1 [2].

$$F(u,v)+S(u,v)+D(u,v)=G(u,v)$$
$$F(u,v)=\Im\{image1\}$$
$$G(u,v)=\Im\{image2\}$$
$$S(u,v)=\Im\{spatialshift\}$$
$$D(u,v)=\Im\{noise\}$$

Fig. 1 Equations of correlation with Fourier Transforms

III. Methodology

18 orange ping pong balls are thrown into the perimeter drain to enhance contrast between the particles and fluid. Thereafter, capture the surface flow images of drain using a camera suspended 3m above the drain. The Images captured will then be fed into MatPIV for analysis.

The MatPIV code written by Sveen and Cowen [4] was modified to analyze the drain flow velocity. This code is able to track the movement of the particles effectively and produced the required vector plot. The code was also developed to create a loop effect. With the loop ability, MatPIV is able to investigate all pictures within two set boundaries e.g. image 50 to image 150.This will greatly save the time during analysis and hugely improved the efficiency of the investigation.

The MatPIV code will allow for velocity vectors plots to be laid over an original image of the drain. With these vectors, the relationship between the surface flow profile and discharges will be established. MatPIV is also able to produce the surface flow velocities in X and Y components at different points and different times in matrix form.

The apparatus required for the experiment are including:

a) 18 numbers of orange ping pong balls.
b) Digital camera with zoom lens and high shutter speed, with ability to take sequential images,
c) A computer with Nikon Camera Control Pro software installed,
d) A computer with Matlab 2006+ and MatPIV installed.

The details of experimental procedures are listed below:

a) Ensure the water in the drain is flowing at a steady state.
b) Ensure the camera is in place and connected to the computer with the settings.
c) Ensure the camera can be activated and set to take pictures.
d) Throw the ping pong balls into the drain and start capturing the picture.
e) Ultilized MatPIV to analyze the captured images.

IV. Results and Discussion

The series of images captured that represent the water flow in the drain will be input into MatPIV, which is written in Matlab. These 9 selected images have clear visualization of the surface flow and therefore accurate vector of the surface flow profile will be plotted. By visual inspection, there is only one flow direction in this study, flowing from right to left.

Basically, the flow direction from right to left will produce negative vectors values in MatPIV and vice versa. Theoretically, as all the flow are flowing from right to left in this study, only negative vectors will be produced. However, there are some vectors directing from right to left. Thus, produce positive values vector (refer to Figs. 2 to 10). This might be because the water depth in the drain is too shallow. The shallow drain water will produce friction between the flow and surface of the drain, thus causing some drawn back of water inside the drain. Moreover, the ping-pong balls floating on the water surface might produce some friction between the ping pong balls and surface flow. All these reasons might slow down the water movement, causing some movement of water particles from left to right, that lead to producing positive vectors.

The magnitudes of the velocity for all captured images are presented in Tables I to IX. Results show that the velocities magnitudes are almost the same throughout the experiment ranging from 0.02m/s to 0.05m/s. This indicates the vectors produced are able to represent the surface flow clearly.

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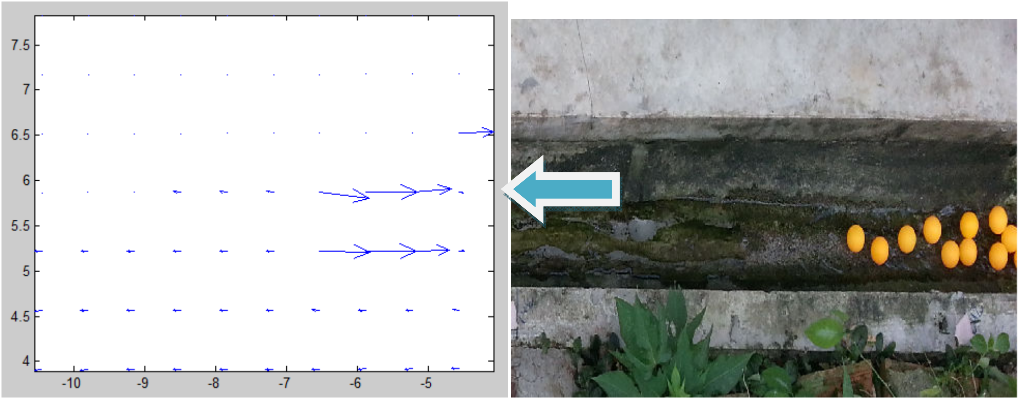
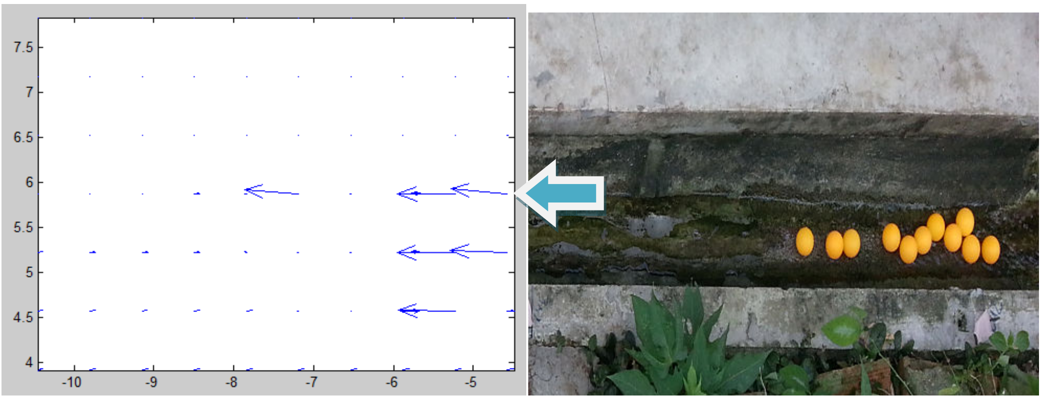


(a) Vector Image 1 (b) Photo Image 1

Fig. 2 Photo and vectors produced for Image 1

TABLE I
VECTOR VELOCITY FOR IMAGE 1

	1	2	3	4	5	6	7	8	9	10
1	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
2	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
3	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.2000
4	NaN	NaN	NaN	-0.0396	-0.0398	-0.0391	0.2877	0.2991	0.2253	0.0273
5	-0.0403	-0.0414	-0.0413	-0.0411	-0.0410	-0.0405	0.2929	0.2927	0.2153	0.0315
6	-0.0414	-0.0427	-0.0425	-0.0424	-0.0425	-0.0421	-0.0430	-0.0413	-0.0379	-0.0338
7	-0.0426	-0.0441	-0.0435	-0.0434	-0.0435	-0.0435	-0.0437	-0.0435	-0.0432	-0.0426



(a) Vector Image 2 (b) Photo Image 2

Fig. 3 Photo and vectors produced for Image 2

TABLE II
VECTOR VELOCITY FOR IMAGE 2

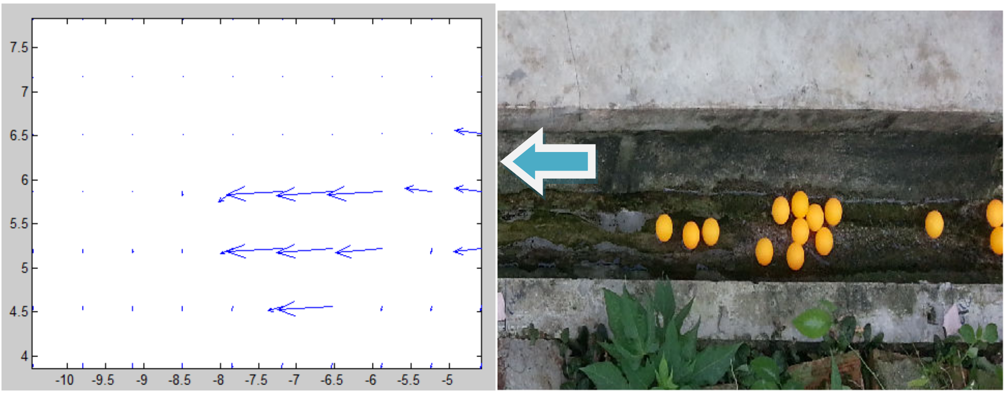
	1	2	3	4	5	6	7	8	9	10
1	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
2	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
3	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.0015
4	NaN	NaN	NaN	0.0999	-0.0303	-1.0050	-0.0243	0.3130	-1.0785	-1.0630
5	0.0919	0.0941	0.1007	0.1011	-0.0268	-0.0229	-0.0235	0.3089	-1.0893	-1.0682
6	0.0925	0.0952	0.0952	0.1010	0.1001	-0.0260	-0.0037	0.2941	-1.0669	0.1262
7	0.0940	0.1003	0.1014	0.1029	0.1048	0.1076	0.1118	0.1158	0.1173	0.1228

(a) Vector Image 3 (b) Photo Image 3

Fig. 4 Photo and vectors produced for Image 3

TABLE III
VECTOR VELOCITY FOR IMAGE 3

	1	2	3	4	5	6	7	8	9	10
1	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
2	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
3	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	-0.2774
4	NaN	NaN	NaN	-1.1946	-1.2027	-1.1968	-0.8261	-0.8699	-0.7860	0.6367
5	-0.0147	-0.0182	-0.0191	-0.0237	-1.2107	-0.2402	-0.8274	-0.8442	-0.7796	-0.0301
6	-0.0123	-0.0175	-0.0189	-0.0230	-0.0253	-0.2402	-0.3214	-0.3277	-0.3297	-0.0295
7	-0.0112	-0.0187	-0.0190	-0.0197	-0.0207	-0.0218	-0.0247	-0.0257	-0.0260	-0.0277



(a) Vector Image 4 (b) Photo Image 4

Fig. 5 Photo and vectors produced for Image 4

TABLE IV
VECTOR VELOCITY FOR IMAGE 4

	1	2	3	4	5	6	7	8	9	10
1	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
2	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
3	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	-0.5281
4	NaN	NaN	NaN	-0.0072	-0.2795	-1.0828	-1.0865	-1.0774	-0.5333	-0.5310
5	-0.0027	-0.0034	-0.0020	-0.0081	-0.2382	-1.0758	-1.0843	-0.9072	-0.0173	-0.5460
6	-0.0026	-0.0025	-0.0020	-0.0073	-0.0155	-0.2831	-1.0756	-0.0210	-0.0177	-0.0186
7	-0.0031	-0.0025	-0.0034	-0.0055	-0.0085	-0.0164	-0.0187	-0.0191	-0.0166	-0.0176

(a) Vector Image 5 (b) Photo Image 5

Fig. 6 Photo and vectors produced for Image 5

TABLE V
VECTOR VELOCITY FOR IMAGE 5

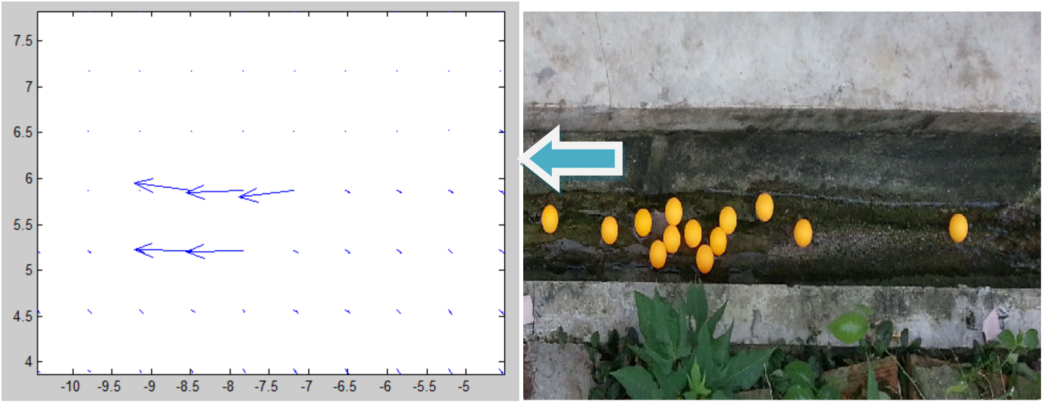
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
2	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
3	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.0604
4	NaN	NaN	NaN	-0.0074	-0.6602	-0.6653	-0.6510	-0.0412	-0.0396	0.0660
5	0.0522	0.0612	0.0522	-0.0019	-0.6211	-0.6627	-0.1573	0.0619	0.0612	0.0667
6	0.0505	0.0544	0.0507	0.0452	-0.5496	-0.6230	-0.1576	0.0624	0.0632	0.0671
7	0.0480	0.0505	0.0500	0.0568	0.0589	0.0612	0.0638	0.0654	0.0651	0.0672

(a) Vector Image 6 (b) Photo Image 6

Fig. 7 Photo and vectors produced for Image 6

TABLE VI
VECTOR VELOCITY FOR IMAGE 6

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
2	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
3	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	1.7815e-04
4	NaN	NaN	NaN	-0.3387	-0.3400	-0.3119	-0.3047	0.0038	0.3352	0.3348
5	1.7776e-04	0.0018	-0.3036	-0.3025	-0.3165	-0.3131	-0.3164	0.0028	0.0027	0.3021
6	-1.1677 e-04	0.0011	-0.3065	-0.3016	-0.3225	-4.9313e-04	9.0120e-04	0.0019	0.0016	0.0018
7	8.5479e-04	0.0013	0.0013	8.4275e-04	-5.6499e-04	2.8375e-04	6.5026e-04	6.0162e-04	0.0018	0.0015

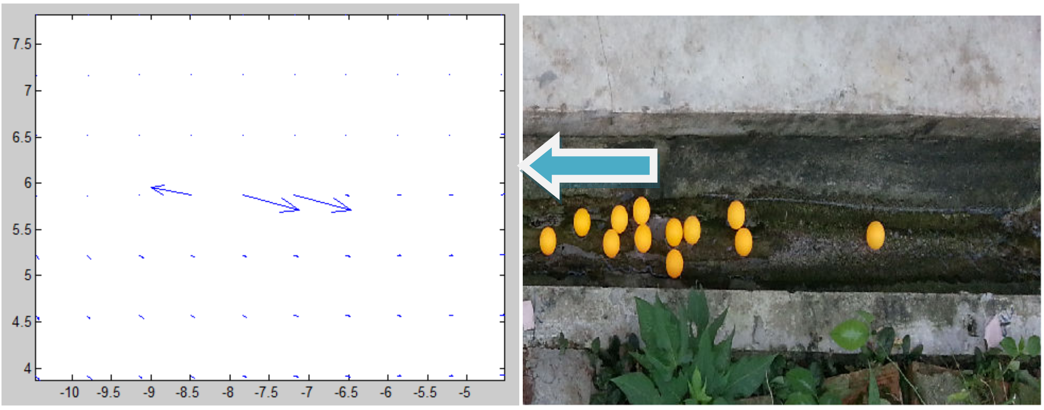


(a) Vector Image 7 (b) Photo Image 7

Fig. 8 Photo and vectors produced for Image 7

TABLE VII
VECTOR VELOCITY FOR IMAGE 7

	1	2	3	4	5	6	7	8	9	10
1	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
2	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
3	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.0437
4	NaN	NaN	NaN	-0.5812	-0.5783	-0.5604	0.0398	0.0411	0.0416	0.0422
5	0.0274	0.0326	0.0414	-0.5828	-0.5795	0.0414	0.0388	0.0401	0.0405	0.0410
6	0.0256	0.0297	0.0309	0.0312	0.0301	0.0378	0.0374	0.0384	0.0394	0.0399
7	0.0234	0.0242	0.0252	0.0267	0.0266	0.0278	0.0308	0.0361	0.0374	0.0384

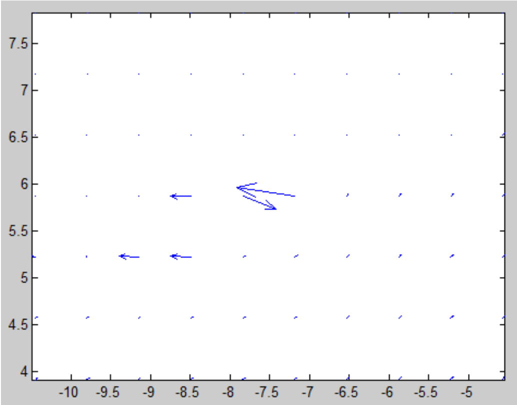


(a) Vector Image 9 (b) Photo Image 9

Fig. 9 Photo and vectors produced for Image 8

TABLE VIII
VECTOR VELOCITY FOR IMAGE 8

	1	2	3	4	5	6	7	8	9	10
1	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
2	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
3	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.0622
4	NaN	NaN	NaN	-0.6884	0.9690	0.9692	0.0602	0.0623	0.0634	0.0647
5	0.0441	0.0514	0.0701	0.0623	0.0617	0.0620	0.0626	0.0636	0.0652	0.0674
6	0.0485	0.0579	0.0650	0.0643	0.0630	0.0635	0.0644	0.0658	0.0681	0.0722
7	0.0601	0.0617	0.0624	0.0642	0.0641	0.0649	0.0667	0.0675	0.0702	0.0766



(a) Vector Image 9

(b) Photo Image 9

Fig. 10 Photo and vectors produced for Image 9

TABLE IX
VECTOR VELOCITY FOR IMAGE 9

	1	2	3	4	5	6	7	8	9	10
1	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
2	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
3	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.0433
4	NaN	NaN	NaN	-0.3709	0.6065	-1.0421	0.0440	0.0437	0.0435	0.0440
5	-0.0425	-0.0011	-0.3636	-0.3628	0.0433	0.0439	0.0439	0.0439	0.0437	0.0443
6	0.0393	0.0402	0.0425	0.0434	0.0431	0.0440	0.0441	0.0442	0.0441	0.0448
7	0.0433	0.0438	0.0433	0.0433	0.0431	0.0435	0.0442	0.0456	0.0456	0.0460

V. CONCLUSION

Results indicate that with the images capturing the movement of ping pong balls inside the drain, MatPIV is able to analyze and track the movement of ping pong balls and the surface flow profile and behavior. The main parameter analyzed by MatPIV is flow vector velocity. Negative values of velocity indicate the flow direction from right to left, where else positive velocity values indicate the movement of ping pong ball from left to right. Besides, experiment results present that the velocities magnitudes are consistent for all the images analyzed. This confirms the vectors produced by MatPIV are able to represent the surface flow clearly.

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