Budapest University of Technology and Economics
Department of Hydraulic and Water Resources Engineering

Analysis of video-based discharge measurement method for streams

(Videó alapú vízhozam-mérési módszer tesztelése kisvízfolyásokra)

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Abstract

The video based discharge measurement method is a novel way to measure streamflow. The method is based on the so called Large-Scale Particle Image Velocimetry (LSPIV). The main idea is to record the free-surface of the stream using video-camera(s) and estimate the flow velocity based on the post-processed images. The main steps of the algorithm are the following: i) transform the images to a orthogonal coordinate system (orthorectification); ii) detect the movement of tracers on the surface using a suitable cross-correlation method; iii) calculation of instantaneous flow velocity vectors for image pairs; iv) estimating a so called index-velocity based on the spatio-temporal averaging of the vector fields. A relationship between the index-velocity and the actual discharge should be set up performing concurrent (calibration) discharge measurements. Once a strong relationship has been established the LSPIV method can be used for continuous discharge measurements. With this indirect technique discharge measurements can be carried out in cases where the conventional methods face difficulties, such as flash floods.

In this study I give an overview about the conventional methods and introduce the LSPIV method. Testing and application of the novel method will be introduced for two case studies: a rectangular channel at a wastewater treatment plant and a natural stream (Által-ér) close to Tata. A sensitivity analysis is done with different settings within the LSPIV software. The relationship between the index-velocity and the discharge is established for both case studies. An attempt will also be made for testing the online application of the method. Finally, the assessment of the LSPIV method will be discussed and future research ideas will be outlined.

Tartalmi kivonat

A videó alapú vízhozam-mérés egy újszerű mérési eljárás. A mérési módszer alapja az ún. Large Scale Particle Image Velocimetry (LSPIV), aminek lényege, hogy egy vagy több videokamerával filmezi a vízfelszínt, majd az alapján a vízfelszín sebességére tesz becslést. Az eljárás leglényegesebb lépései a következők: i) a videó képkockáit derékszögű koordináta-rendszerre transzformáljuk; ii) egymást követő képpárokon egy kereszt-korrelációs algoritmus segítségével a vízfelszínen utazó jelzőanyagok elmozdulását detektáljuk; iii) A foltok elmozdulása alapján pillanatnyi sebességvektor mezőket állítunk elő, iv) A vektormezők térbeli és időbeli átlagolásával minden mérési állapothoz egy ún. index-sebességet állítunk elő. Kiegészítő (kalibráló) vízhozam-mérésekkel az index-sebesség és a vízhozam között kapcsolatot állítunk fel különböző vízjárási állapotokra. Ha ez a kapcsolat igazoltan erős, a későbbiekben a videofelvételek célirányos elemzése elegendő a vízhozam meghatározásához és nincs szükség párhuzamos mérésekre. Ezzel az eljárással indirekt módon végezhetünk vízhozam-mérést olyan esetekben is, amikor a hagyományos eljárások végrehajtása nem megoldható (pl. villámárvizek, nehezen megközelíthető helyek), elősegítve ezzel a megbízhatóbb terepi adatgyűjtést.

A dolgozatban áttekintem a hagyományos vízhozam-mérési módszereket, majd ismertetem az LSPIV módszer alapelveit. Az új mérési eljárás tesztelését és alkalmazását két esettanulmányon keresztül illusztrálom, amelyek közül az első egy szennyvíztelep téglalap szelvényű csatornája, a második pedig az Által-ér tatai szelvénye. Érzékenységvizsgálatot hajtok végre az LSPIV módszer paramétereire, majd mindkét esetre elvégzem a vízhozam és index-sebesség közötti kapcsolat felállítását. Kísérletet teszek továbbá a módszer online alkalmazásának tesztelésére is. A dolgozat végén értékelem a vizsgálataim eredményeit, megfogalmazom az LSPIV módszer előnyeit-hátrányait és továbbfejlesztési javaslatokat fogalmazok meg.

1 Introduction

Continuous monitoring of discharge in rivers is important from several aspects such as engineering or environmental investigations, however, it is still a challenging and not adequately solved issue. The video based discharge measurement method is a promising manner to measure streamflow and might be a suitable way to have such a continuous flow monitoring tool. This indirect method is based on the so called Large-Scale Particle Image Velocimetry (LSPIV). The main idea is to record the free-surface of the stream using high quality calibrated video camera(s). The main steps of the algorithm are the following: i) transform the images to an orthogonal coordinate system (orthorectification); ii) detect the movement of tracers on the surface using a suitable cross-correlation method; iii) calculation of instantaneous flow velocity vectors for image pairs; iv) estimating a so called index-velocity based on the spatio-temporal averaging of the vector fields. A relationship between the index-velocity and the actual discharge should be set up performing concurrent (calibration) discharge measurements. Once a strong relationship has been established the LSPIV method can be used for continuous discharge measurements. With this indirect technique discharge measurements can be carried out in cases where the conventional methods face difficulties, such as flash floods.

LSPIV has already been tested in different countries. The development of the method and the first applications were conducted in Japan (Fujita et al., 1998) and in the US (Muste et al., 2008). Despite the encouraging foreign attempts no video-based discharge measurement has been developed in Hungarian rivers before. This study is the first testing of the Large-Scale Particle Image Velocimetry for discharge measurements in Hungary.

The method itself is reasonably straightforward, however, there are several conditions which have to be ensured for good quality measurements. Besides its simplicity LSPIV could also answer some problematic questions related to stream flows. For instance, there is a known limitation of the stage-discharge relationship which is conventionally used for discharge estimation. Especially in smaller rivers and streams the hysteresis effect shows up leading to different discharge values at the same stage for rising and falling limb of a flood wave (Figure 1). For measurement point of view, flash floods are also a problem. The flood wave propagation can be very fast, giving no chance for expeditionary measurements. As will be shown later on, if a webcam was installed on the field and an algorithm could process the images permanently, we could perform continuous real-time discharge data collection. We believe, that the LSPIV method can be a suitable manner to indirectly measure streamflow due to its capabilities and simplicity and this study will prove its applicability in the field.

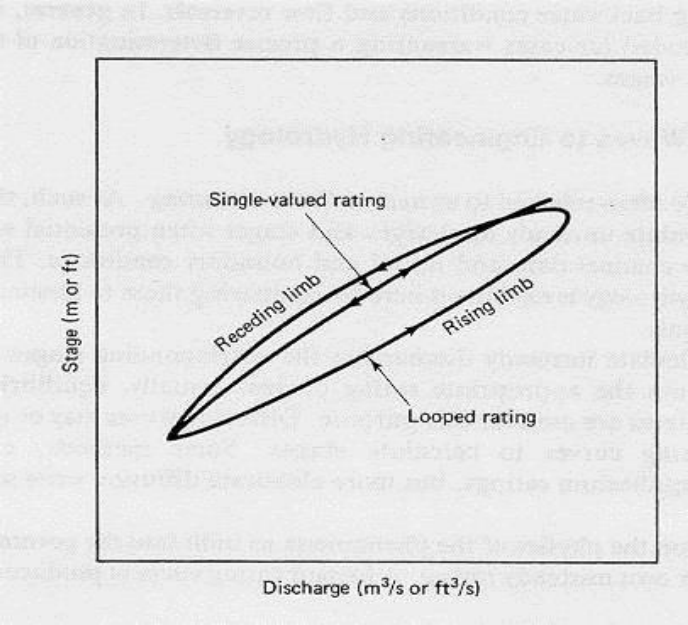


Figure 1. Unseady discharge-stage curve
[source: http://parra.sdsu.edu/textbookhydrology300fig9-9.html]

In this study I give an overview about the conventional methods and introduce the LSPIV method. Testing and application of the novel method will be introduced for two case studies: a rectangular channel at a wastewater treatment plant and a natural stream (Által-ér) close to Tata. A sensitivity analysis is done with different settings within the LSPIV software. The relationship between the index-velocity and the discharge is established for both case studies. An attempt will also be made for testing the online application of the method. Finally, the assessment of the LSPIV method will be discussed and future research ideas will be outlined.

2 Conventional discharge measurement methods

Discharge is the volume of water that flows past a certain point in a stream over a specific period of time, usually expressed in cubic meter per second. Also it can be computed by multiplying the area of water in a channel cross-section by the average velocity of the water in that cross-section.

Water discharge measurements can be done by numerous ways. These are the most commonly used methods:

- Acoustic Doppler Current Profiler
- Point-in velocity measurements
- Volumetric
- Portable measuring weirs and flumes
- Formulas for discharge estimation

2.1 Acoustic Doppler Current Profiler

The Acoustic Doppler Current Profiler (ADCP) (Figure 2) is one of the most frequently used devices for discharge measurement. Using this tool the reasonably accurate discharge measurement can be done in a fast and straightforward manner. The ADCP uses the principles of the Doppler effect to measure the velocity of the water by sending a sound pulse into the water and measuring the change in the frequency of that sound pulse reflected back to the ADCP by sediment or other particulates being transported in the water (see a more detailed description of the ADCP operation e.g. here: Baranya, 2010). As additional information, the device receives signals from the bottom of the stream so it also measures water depth.

Figure 2. Acoustic Doppler Current Profiler [source: www.rdinstruments.com]

ADCP is mounted onto a boat with its acoustic beams placed below the water surface looking down to the bottom (Figure 3). During measurement the instrument is guided across the river channel to measure velocities and depths. The river-bottom tracking capability of the ADCP acoustic beams or a Global Positioning System (GPS) is used to track the progress and provide width measurements.

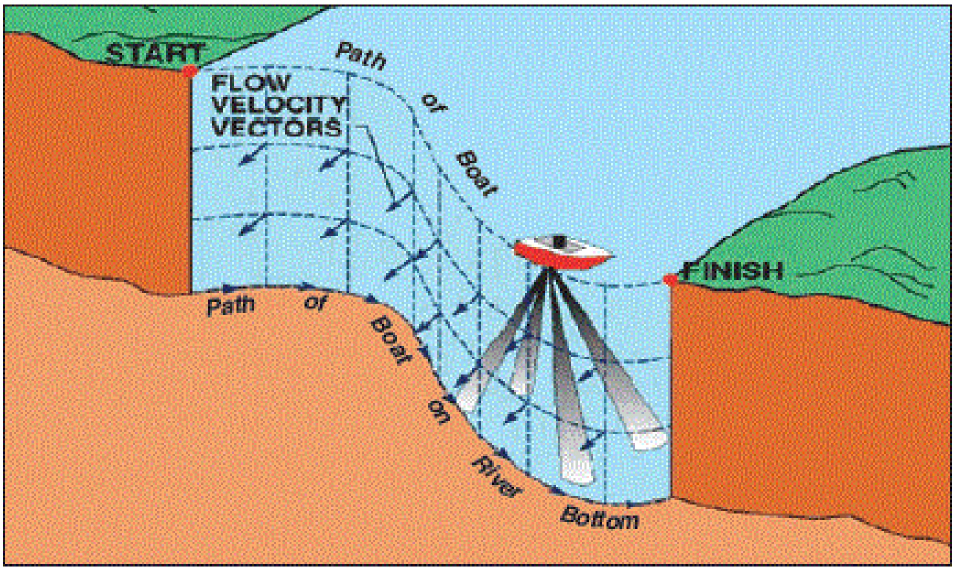


Figure 3. ADCP on a moving boat
[source: http://water.usgs.gov/edu/streamflow2.html]

Based on the depth and width measurements a post-processing software calculates the area for each measurement cell. Then using the discharge = area × velocity specific discharges are being calculated, and integrating them over the entire cross-section total discharge is resulted (Figure 4). There are other acoustic meters that can be permanently installed such as the *Acoustic Doppler Current Meter* (ADCM) and the *Acoustic Velocity Meter* (AVM). These instruments are capable of acquiring continuous data collection.

Due to the size and the measurement limitations of ADCPs it is rather the large streams and rivers where this method can be adequately used. For smaller streams of a width of couple of meters, preferably the methods presented in the following points are applied.

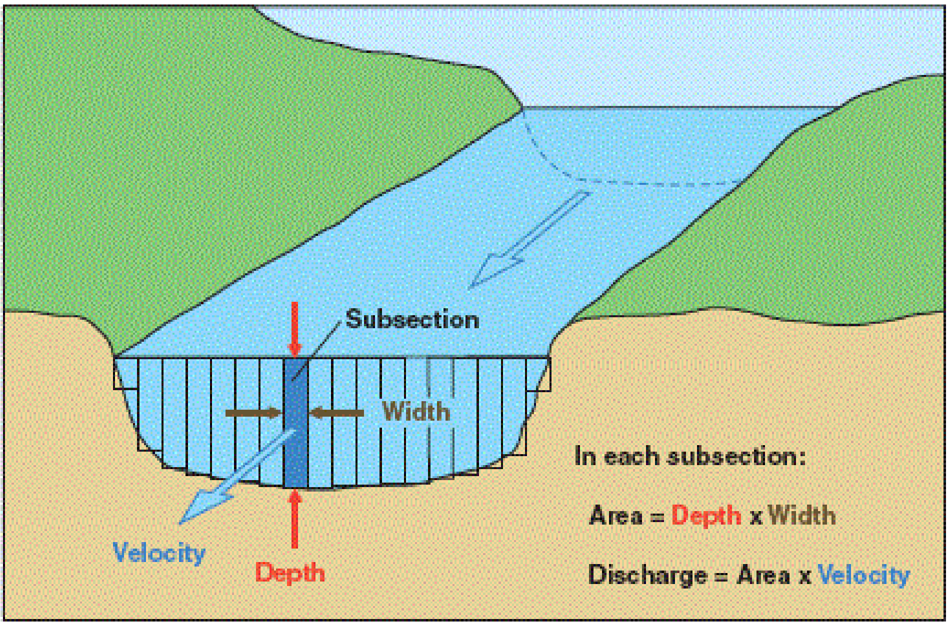


Figure 4. Discharge calculation
[source: http://water.usgs.gov/edu/streamflow2.html]

2.2 Point-in velocity measurements

In smaller and shallower streams, where the width of generally smaller than 5-10 m and the depth is smaller than 1 m, the above introduced method with ADCP is generally not applicable. In such cases it is e.g. the point-in velocity measurement method which can be used instead. In this technique current meters are used to measure velocities and sounding devices to measure depths at fixed locations on a cross-section. Width is generally measured using a wire or steel tape. If direct ways are not possible for some reason, the stream width can be measured with optical or electronical distance meters or using GPS. The velocity of the streamflow is measured using a current meter. The most commonly used one in the US is the Price AA current meter (Figure 5), but very similar ones are being used in Europe, too. It has a wheel of six metal cups that revolve around a vertical axis. An electronic signal is transmitted by the meter on each revolution allowing the revolutions to be continued and timed. The rate of the cups revolving is directly related to the flow velocity, hence the timed revolutions are used to determine the velocity. Price AA meter can be attached to a wading rod or suspended from a cable. Another example for current meters for shallow water is the Pygmy Price, which is attached to a wading rod. The size is somewhat smaller than the Price AA's.

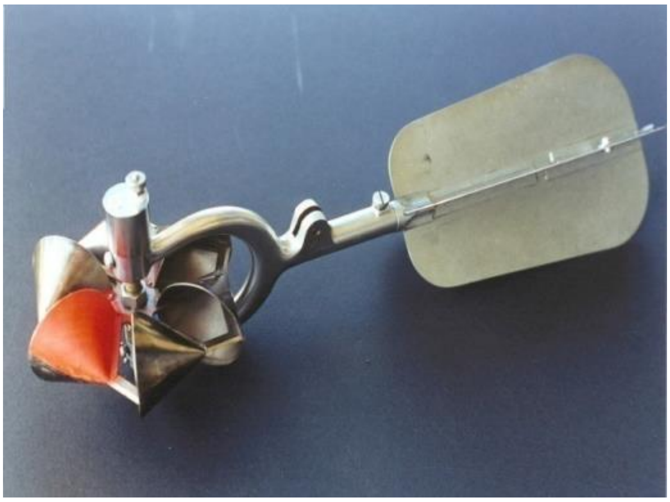


Figure 5. Price AA current meter
[source: http://www.state.nj.us/dep/wms/shvanda_stream_gaging.pdf]

For point-in velocity measurements Acoustic Doppler Velocimeters (ADV) (Figure 6) can also be used. It works by the same principles as the ADCP, but ADV is attached to a wading rod and measures one single velocity value at a point (e.g. Voulgaris and Trowbridge, 1998). Computing discharge with current meter or ADV are both done by calculating the areas of each subsection from the width and depth measurements and then multiplying by the measured velocities. The total discharge comes from summing up the specific discharge values of each subsection.

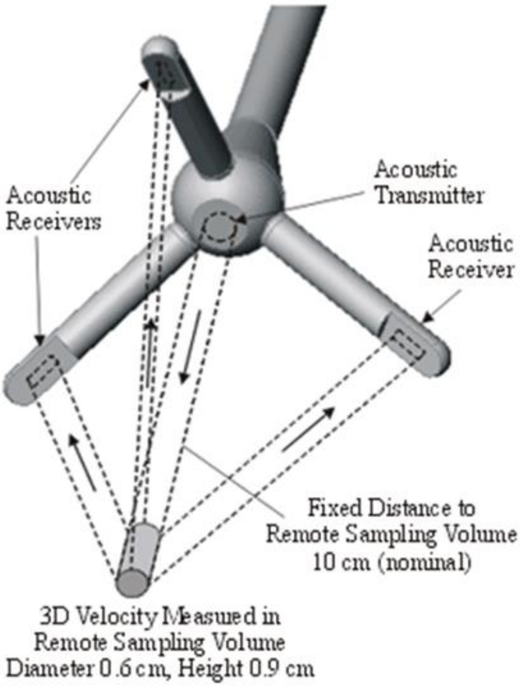


Figure 6. Acoustic Doppler Velocimeter
[source: www.sontek.com]

2.3 Volumetric method

The volumetric method is a very simple way to measure discharge (Hajnal and Koris, 2014). It captures the flow into a container of known volume and measures the time taken to fill the container (Figure 7). The time is measured with a stopwatch. There are a couple of rules to note like the filling time has to be higher than ten seconds and the container has to be calibrated. At least ten separate filling measures are needed. Then the discharge = volume / time. Multiple measurements shall be averaged for the final discharge result.

Figure 7. Volumetric discharge measurements method
[source: http://www.state.nj.us/dep/wms/shvanda_stream_gaging.pdf]

2.4 Portable measuring weirs and flumes methods

The most commonly used one of the portable flumes is the so called *Parshall flume* (Figure 8). It constricts the open channel flow for measurements of low flow on shallow, slow moving or steep gradient streams. There is a pre-defined relation between the water level upstream and flow through constriction.

Figure 8. Discharge measurement with a portable Parshall Flume [source: http://www.state.nj.us/dep/wms/shvanda_stream_gaging.pdf]

2.5 Formulas for discharge estimation

There are indirect methods which are only to be used when the flow conditions are too dangerous to use the current meters and sounding devices for field measurements. Any of these discharge estimations cannot count as highly reliable methods. The so called "Slope-Area method" uses the Manning equation. The velocity in a reach is related to the slope of the channel and to the roughness of the bed material.

$$Q = A \cdot V$$

$$V = k \cdot R^{\frac{2}{3}} \cdot S^{\frac{1}{2}}$$

where *A* is the wetted cross-section area, *V* is the cross-section averaged velocity, *k* is the Manning-smoothness, *R* is the hydraulic radius and *S* is the slope. In case of detected water levels and known cross-section geometries at gauges along a stream reach the *R* and *S* parameters can be calculated and *k* is to be estimated based on the bed material and vegetation properties.

Another indirect method, the "Contracted-Opening" method uses the contraction of a stream channel by a bridge which creates an abrupt drop in the water surface elevation between an approach section and the contracted section under the bridge. This contracted section frames by the bridge abutments and the channel bed can be used to estimate flood flows. High water marks and the geometry of the bridge and the channel are used in this method.

3 Video-based discharge estimation

The main advantage of the herein introduced method, the Large Scale Particle Image Velocimetry (LSPIV), is that there is no need to perform direct measurements in the stream during the discharge detection, however, it does need a thorough preliminary calibration process (Muste et al., 2008). Compared to empirical and semi-empirical methods, on the other hand, this is mainly physically based as we measure the flow velocity on the free surface of the stream and use this information to gain cross-sectional discharge.

3.1 Recording of flow

The determination of the free-surface velocity distribution is needed to make estimations on the flow discharge in this procedure. An indirect method is used to collect this information. A calibrated video camera (preferably a high definition one (HD)) is needed with a fix place to record a certain area of the stream surface. If possible the video camera should be right above the stream or in an oblique angle from the river bank. This can generally be ensured by mounting the device on a bridge or a high enough building. Large areas, even hundreds of square meters can be recorded. As one of the most crucial application criteria some sort of tracer is necessary for the video processing method to track. It can be natural material like sediments, foams, bubbles created by turbulence or it can be artificial material like plastic particles, candles, etc. As Figure 9 shows, once the video has been recorded the raw images need to be transformed onto a truly 2D system (this step is the “orthorectification”) and then the Particle Image Velocimetry procedure can be performed to reveal the surface velocity distribution.

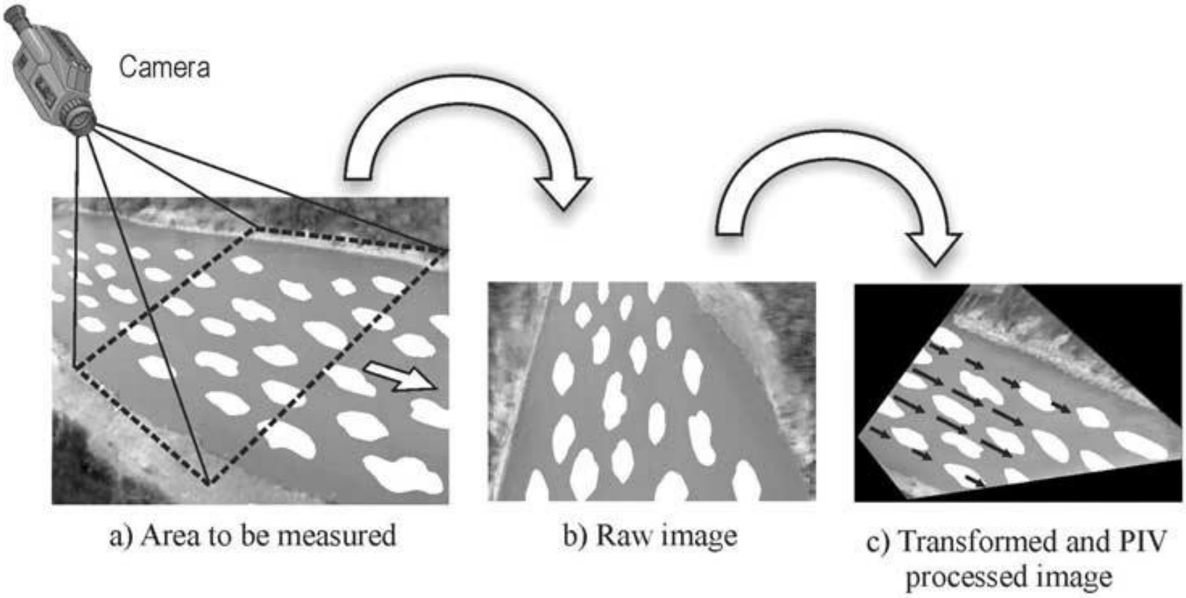


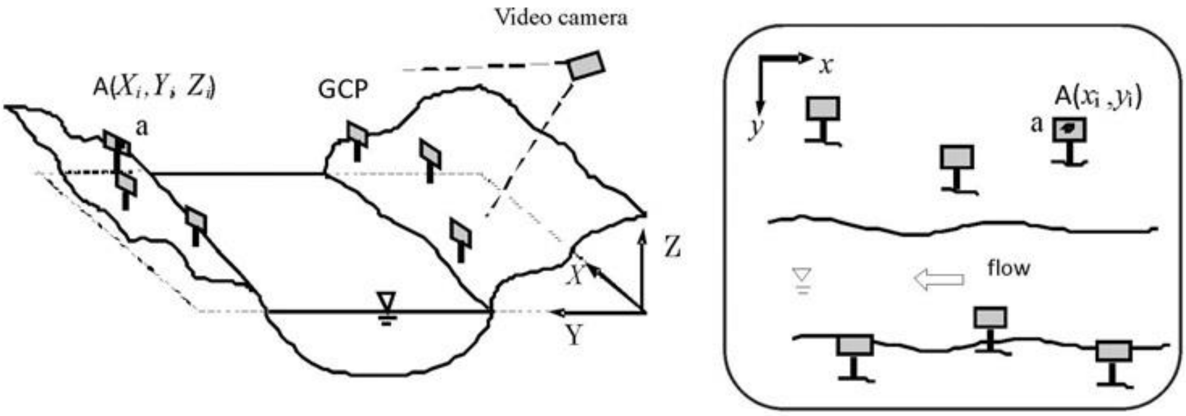
Figure 9. LSPIV measurement sequence (Muste, 2008)

3.2 Image orthorectification

The video recordings are done from the river bank or from a bridge. In order to extract accurate flow data from the recorded images (i.e. to have undistorted, 2D images), they have to be rectified by an appropriate image transformation scheme (Mickhail and Ackermann, 1976). A conventional photogrammetric relation is applied to produce orthoimages using known coordinates of ground control points (GCPs or reference points) in the real (X, Y, Z) and the image (x, y) coordinate systems, as shown in Figure 10. The relationship between the two systems is (Fujita et al., 1998):

$$x = \frac{A_1X + A_2Y + A_3Z + A_4}{C_1X + C_2Y + C_3Z + 1}, \quad y = \frac{B_1X + B_2Y + B_3Z + B_4}{C_1X + C_2Y + C_3Z + 1},$$

A minimum of 6 GCPs are needed, but 10 is recommended (Figure 10). The control point selection is often dictated by accessible objects in the field (e.g., trees, power line poles, building corners).



(a) Ground coordinates (X,Y,Z) (b) Image coordinates (x,y)

Figure 10. Relationship between camera and field coordinates (Muste, 2008)

3.3 Image processing

LSPIV algorithms use a pattern matching technique to image intensity distribution in a series of images as illustrated in Figure 11. The similarity index enclosed in a small interrogation area (IA) fixed in the first image is calculated for the same-sized window within a larger search area (SA) selected in the second image. The window pair with the maximum value for the similarity index is assumed to be the pattern's most probable displacement between two consecutive images. Once the distance between the centers of the respective small window is obtained, velocity can be calculated by dividing it with the time difference (dt) between consecutive images. This searching process is applied to all interrogation area in each image.

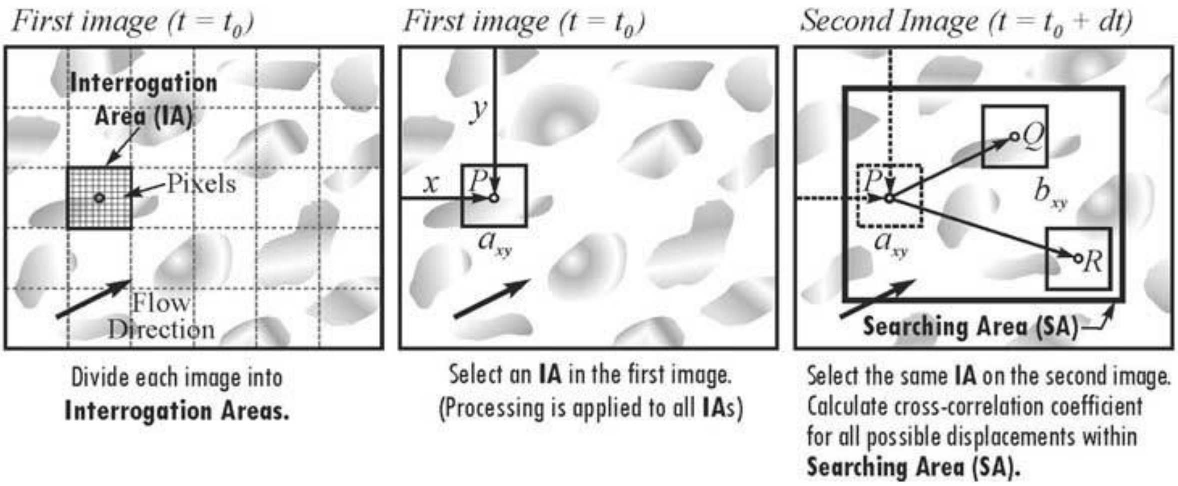


Figure 11. Interrogation Area and Searching Area

Muste and Fujita’s algorithm uses cross-correlation coefficient as a similarity index. Cross correlation is computed between the interrogation area (IA) in the first image and the interrogation areas located within the search area (SA) in the second image. The pair of particles showing the maximum of cross-correlation coefficient is selected as a candidate vector. In this method, the cross-correlation method, R_{ab} is defined as

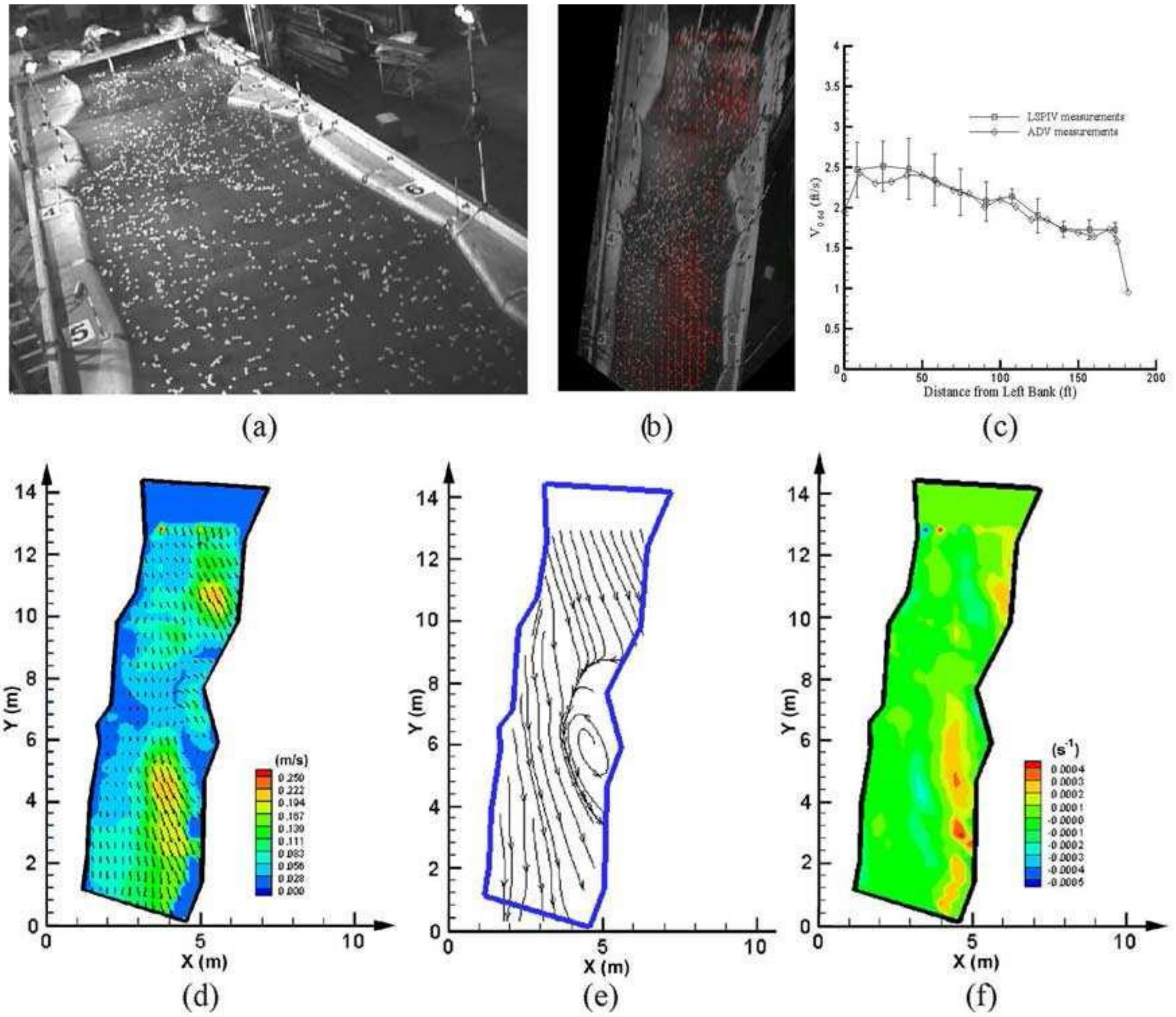
$$R_{ab} = \frac{\sum_{x=1}^{MX}\sum_{y=1}^{MY}\left\{\left(a_{xy}-\bar{a}_{xy}\right)\left(b_{xy}-\bar{b}_{xy}\right)\right\}}{\left\{\sum_{x=1}^{MX}\sum_{y=1}^{MY}\left(a_{xy}-\bar{a}_{xy}\right)^2\sum_{x=1}^{MX}\sum_{y=1}^{MY}\left(b_{xy}-\bar{b}_{xy}\right)^2\right\}^{1/2}}$$

where MX and MY are the sizes of the interrogation areas and a_{xy} and b_{xy} are the distributions of the gray-level intensities (ranging from 0 to 255 for an 8-bit image). The overbar indicates the mean value of the intensity for the IA. For improving the measurement accuracy, subpixel peak detection methods using Gaussian fitting or parabolic fitting is applied to the cross-correlation distribution (Fujita et al, 1998).

The algorithm uses a variance normalized correlation, in which each pixel in the IA is equally weighted, such that the background is just as important as the particle images. A major advantage of the algorithm that it can estimate velocities from low-resolution images too, captured even with standard video cameras.

3.4 Measurement outcomes

The raw LSPIV measurement outcomes are instantaneous vector fields. The technique itself is only available that provides instantaneous velocity measurements on a plane. However, in the post-processing stage the LSPIV program can determine mean velocity field, streamlines as well as vorticity.



(a) (b) (c)

(d) (e) (f)

Figure 12. LSPIV results (Muste, 2008) (a) video frame of the upstream reach of a 5 m × 40 m hydraulic model, (b) instantaneous vector field superposed on an undistorted video frame, (c) comparison of LSPIV velocities with ADV velocities in cross section, (d) mean vector field, (e) streamlines established on the mean vector field, and (f) vorticity field established from the mean vector field.

LSPIV estimates discharge using the velocity area method (VAM). The channel bathymetry can be obtained from direct surveys using specialized instruments (e.g., ADCP). The bathymetry can be surveyed at the time of the LSPIV measurements. Surface velocities at several points along the surveyed cross-section are computed by linear interpolation from neighboring grid points of the LSPIV estimated velocity fields. Assuming that the shape of the vertical velocity profile is the same at each point, the depth averaged velocity at each vertical is related to the free-surface velocity by a velocity index. The discharge for each river subsection is computed following the classical VAM procedure.

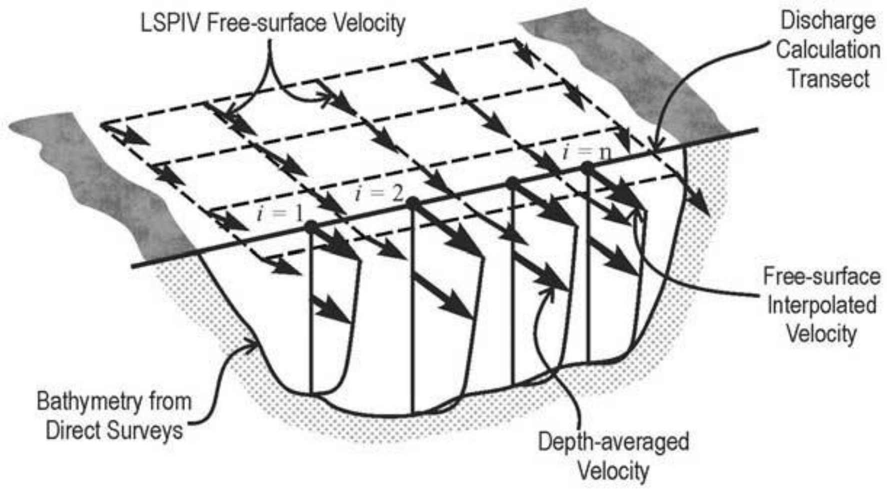


Figure 13. LSPIV-based discharge measurement procedure

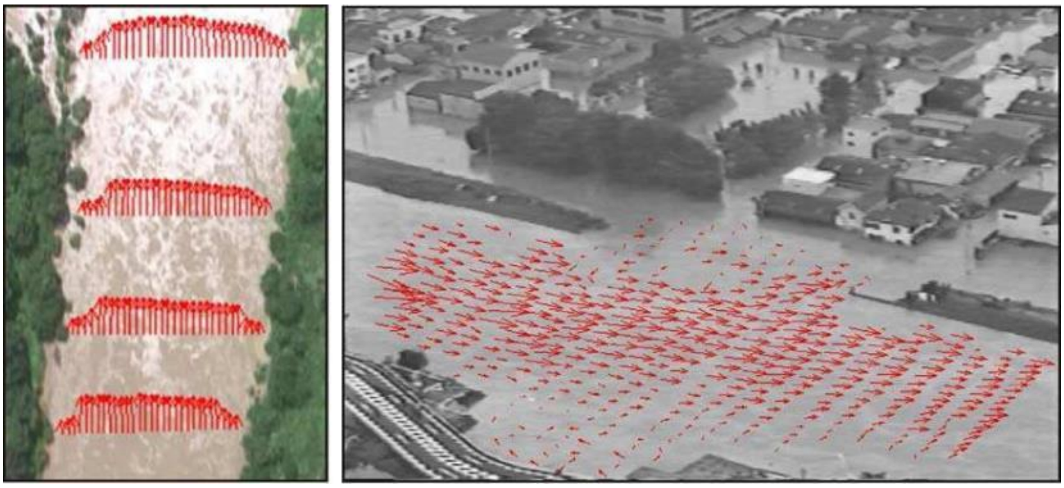


Figure 14. Mean flow distribution during floods measured from helicopter (Japan): (on the left) cross section in the Katsure River (river width 90 m) and (on the right) flow distribution measured during a levee breach on the Shinkawa River (river width 80 m)

In this study we are going to apply the index velocity method to measure flow discharge in the streams as it was introduced by Huang (2006) for horizontal ADCP studies. The principle of Index-velocity method is to establish a rating for the relationship between the channel mean velocity and Index-velocity. Water level may be also a parameter for the rating. In this situation the Index-velocity is an average velocity measured at a local area over the studied water surface.

Discharge is calculated by: $Q = A \cdot V$

where V = channel mean velocity, A = wetted area in channel cross-section. The wetted area is a function of cross-section geometry and water level. For a given site, it is a function of water level only:

$A = \mathrm{f}(Z_s)$

where Z_s = water surface level referring to a local datum. The stage-area rating is usually presented as a table or curve for a site. A general form of Index-velocity rating is as follows:

$V = \mathrm{f}(V_\mathrm{I}, H)$

where V_I = Index-velocity, f =velocity rating model.

In most cases, channel mean velocity is a function of Index-velocity only:

$V = \mathrm{f}(V_\mathrm{I})$

To find the f function, a calibration procedure is needed, which uses data from concurrent flow measurements (with e.g. ADV or ADCP). A regression analysis can support to establish the relationship between V and V_I. A number of analytic models may be used for index-velocity rating (see the table below). The most common one is linear model. But it can also be non-linear or compound that may consist of two or more rating equations.

Rating model	**Mathematical expression**
Linear (one parameter)	$V = b_1 + b_2 V_I$
Second-order polynomia	$V = b_1 + b_2 V_I + b_3 V_I^2$
Power law	$V = b_1 V_I^{b_2}$
Compound linear	$V = b_1 + b_2 V_I \quad V_I < V_C$ $V = b_3 + b_4 V_I \quad V_I \geq V_C$
Two parameter linear	$V = b_1 + (b_2 + b_3 H) V_I$

4 Testing of the Large-Scale Particle Image Velocimetry (LSPIV)

As seen from the previous points the LSPIV method provides an indirect way to detect flow discharges in streams. The methodology certainly has limitations which have to be thoroughly analyzed when a new application is to be established. One of the potential bottlenecks is the lack of tracer at the study site. Also, the settings within the LSPIV algorithms are important as some of them might show significant sensitivity to the measurement results. Furthermore, to use the LSPIV method as a discharge monitoring system, a preliminary calibration process needs to be performed to set up the relationship between the free surface velocities (index velocity in the followings) and the cross-section averaged velocity which is used for calculating the discharge (according to the continuity equation) as shown previously. In this study, two pilot studies will be implemented: a rectangular channel at a wastewater treatment plant and a natural stream (Által-ér) close to Tata. The goal of the first study is to perform a detailed sensitivity analysis on the parameters used in the LSPIV method, whereas in the second case study we will make one more step and set up an on-line discharge measurement system using LSPIV. In both cases we make an attempt to calibrate the LSPIV based discharge measurement method with concurrent discharge measurements.

4.1 Testing of LSPIV on a rectangular channel

4.1.1 The measurement field

The measurements have been done in a channel of a wastewater treatment plant with a Parshall flume in Gödöllő, where the clarified wastewater is conducted into a stream. The Parshall flume (Figure 15), placed in the channel, is a device to measure flow discharge using the backwater effect (which is related to the flow discharge) caused by an artificial contraction in the channel. The channel cross-section is rectangular, consequently the discharge calculation was pretty straightforward based on the flow velocities and the flow depth in the channel (this was one of the reasons we chose this place was for the testing purposes). The conditions for LSPIV measurements at the site were suitable, because, for instance, the video camera could easily be mounted right above the channel (Figure 16). It is, however, more important to note that due to a weir, built in the channel upstream of the Parshall flume, the mixing water results in a significant amount of foam travelling on the water surface. As already mentioned before, it is essential for the LSPIV method to have well recognizable patches on the water surface. For this purposes the foam was perfect. The original idea was to record the water surface while measuring the flow discharge with a different technique, as well as water levels and repeating the measurements several times at different flow situations. Based on the concurrent measurements the aim was to set up the relationship between the index velocity (based on LSPIV) and the flow discharge (based on the concurrent measurements). The measurements took place between 4 am and 4 pm on the 15th July 2015 during which the flow conditions varied significantly (due to the water use in the neighboring settlements). Due to the normal operation of such a wastewater treatment plan the changes in the flow conditions were very dynamic, which, in fact, resulted in some uncertainty of the testing, as will discussed later on.

Figure 15. Parshall flume

Figure 16. Rectangular-section channel

4.1.2 Used measurement methods

To calibrate the indirect, LSPIV based discharge measurement method, we needed concurrent flow discharge measurements. In this case the *Vectrino* Acoustic Doppler Velocimeter (ADV) (Figure 17) was used to measure point-in velocities in one section of the channel to calculate the discharge (Figure 19) (see description of ADV e.g. here, Voulgaris and Trowbridge, 1998). Then the *Leica Sprinter 50* digital leveling instrument was used to measure water levels and the channel bottom level to calculate the water depths (Figure 20).

Figure 17. ADV Vectrino

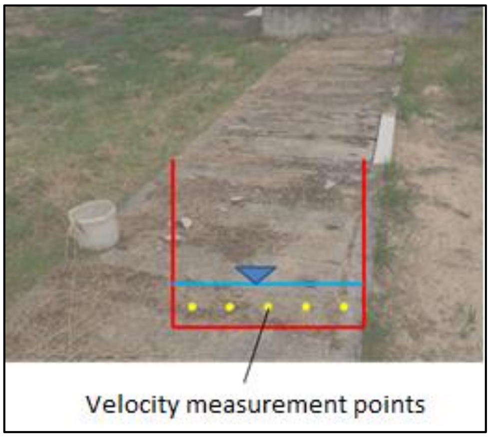


Figure 18. Channel cross-section

Figure 19. ADV measurement

Figure 20. Leica digital leveling instrument

There were 19 measurements performed during the 12-hour-long testing. At each of them a 90 second long video was recorded of the water surface, furthermore, flow velocity measurements at all 5 points in the section (Figure 18) and the water level measurements. One whole measurement took cca. 15 minutes. It was repeated in every half an hour. One point-in velocity measurement took around 2 minutes based on which a time-averaged velocity value was calculated for each point. Since the study cross-section of the channel was divided equally, the average of the 5 point-in velocities could be used to calculate the flow discharge using the continuity equation: $Q = v \cdot A$ (v: cross-section averaged velocity, A: wetted area). The water levels were measured twice during the 15-min-long test measurement, at the start and at the end. The calculated water depth for the given flow condition came from the average of those two. Table 1 shows the five measured time-averaged velocities, the measured flow depths, the calculated cross-section averaged velocities and the calculated flow discharges, respectively for the 19 test measurements. Based on this, a stage-discharge relationship was developed (Figure 21). This curve was actually needed to calibrate the Parshall-flume, but for the LSPIV method calibration the calculated flow discharge values were primarily used as it will be shown in the followings. It is worth noting that the points in Figure 21 show some scattering which can be explained with the reasonably dynamic changes of the flow conditions, i.e. during one 15 minute-long testing measurement there could easily occur significant variation in the flow depth and the discharge. With the ADV based measurements this issue could not be easily managed as this sort of flow discharge measurement technique is relatively time-consuming.

Number of measure-ment	v_1 [m/s]	v_2 [m/s]	v_3 [m/s]	v_4 [m/s]	v_5 *[m/s]*	h_1 [m]	h_2 [m]	B [m]	v_{av} [m/s]	**h_{av} [m]**	Q [m^3/s]	**Q [m^3/h]**
1	0.20	0.21	0.36	0.33	0.11	0.09	0.08	1.05	0.24	**0.085**	0.0215	**77**
2	0.42	0.37	0.29	0.27	0.26	0.035	0.087	1.05	0.32	**0.061**	0.0206	**74**
3	0.23	0.37	0.35	0.37	0.20	0.075	0.051	1.05	0.30	**0.063**	0.0201	**72**
4	0.24	0.37	0.26	0.35	0.18	0.07	0.095	1.05	0.28	**0.0825**	0.0243	**87**
5	0.27	0.33	0.57	0.45	0.00	0.062	0.067	1.05	0.32	**0.0645**	0.0219	**79**
6	0.53	0.47	0.46	0.42	0.13	0.071	0.086	1.05	0.40	**0.0785**	0.0333	**120**
7	0.55	1.00	1.25	0.50	-0.04	0.068	0.088	1.05	0.65	**0.078**	0.0534	**192**
8	0.40	0.80	0.97	0.72	-0.07	0.11	0.089	1.05	0.57	**0.0995**	0.0591	**213**
9	0.74	1.05	1.26	0.74	-0.09	0.092	0.074	1.05	0.74	**0.083**	0.0643	**232**
10	0.58	1.04	0.99	0.57	0.03	0.094	0.091	1.05	0.64	**0.0925**	0.0622	**224**
11	0.75	1.04	0.81	0.53	-0.07	0.09	0.107	1.05	0.61	**0.0985**	0.0633	**228**
12	0.66	1.00	0.83	0.81	0.04	0.093	0.132	1.05	0.67	**0.1125**	0.0789	**284**
13	0.78	0.95	1.06	0.76	-0.08	0.091	0.091	1.05	0.70	**0.091**	0.0664	**239**
14	0.67	0.97	1.27	0.60	-0.08	0.106	0.105	1.05	0.69	**0.1055**	0.0760	**274**
15	0.73	1.02	1.22	0.78	0.32	0.157	0.099	1.05	0.81	**0.128**	0.1093	**394**
16	1.48	1.28	0.81	0.55	0.00	0.065	0.079	1.05	0.82	**0.072**	0.0622	**224**
17	0.71	0.55	1.26	1.08	1.33	0.101	0.109	1.05	0.98	**0.105**	0.1086	**391**
18	0.65	0.92	0.82	0.46	-0.13	0.092	0.102	1.05	0.55	**0.097**	0.0556	**200**
19	0.58	0.80	0.60	0.84	-0.12	0.131	0.083	1.05	0.54	**0.107**	0.0605	**218**

Table 1. Discharge calculation for the Q-H relationship

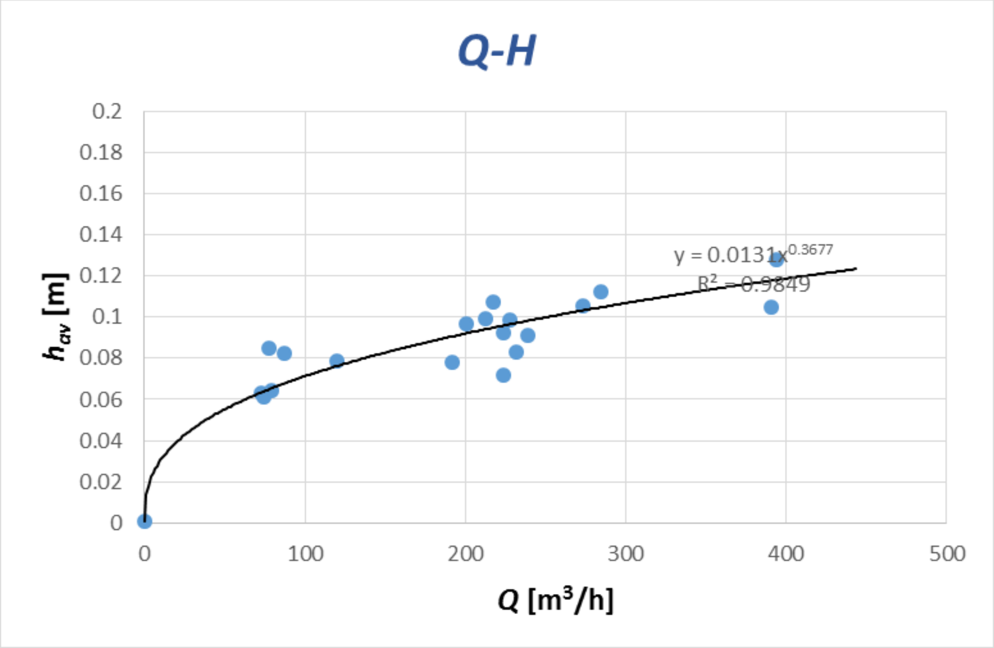


Figure 21. The Q-H relationship

Besides the acoustic flow measurements the main focus was on the LSPIV based velocity measurements. For this purpose a *GoPro* action camera (Figure 22) was used to record the water surface. It was mounted on a stand as Figure 23 shows below. The video camera was remote controlled with a smartphone using the *GoPro* application. To support the orthorectification of recorded images, as one of the crucial element of the LSPIV process, there were 6 Ground Reference Points (GRPs) marked on the ground with known coordinates. 19 videos were taken during the same number of discharge measurements. Water levels next to the video camera were also measured.

Figure 22. Used GoPro Camera

[source: www.shop.gopro.com]

Figure 23. Camera and stand applied

Figure 24. Raw image recorded by the GoPro

4.1.3 The LSPIV procedure

At this phase of my study a manual procedure was performed for the velocity analysis as introduced in the followings. The video camera was recording with a so called fisheye effect (Figure 24). At the very first step of the processing, this effect was removed using the software called *GoPro Studio*. Then, the software called *Virtualdub* was used to convert videos into frames as the LSPIV method uses a series of images instead of the raw video. 5 frames per second (fps) were chosen because the moving foams seemed to be still followable by eye between two frames, which is a good indicator of the suitability.

Preliminary tests showed that higher fps is simply not necessary at the surface velocity. On the other hand, using too few frames, i.e. lower fps, the shape of the foams change too much between two images and the recognition of the patterns shows difficulties. The *Fudaa-LSPIV* program was used to perform the LSPIV analysis and to estimate the surface velocity vectors (Jodeau et al., 2013). A 90-second-long video considering 5 fps time resolution resulted in 450 images as input data for the LSPIV software. Next, the X, Y, Z coordinates of the reference points were defined (Figure 25) as basic information for the orthorectification.

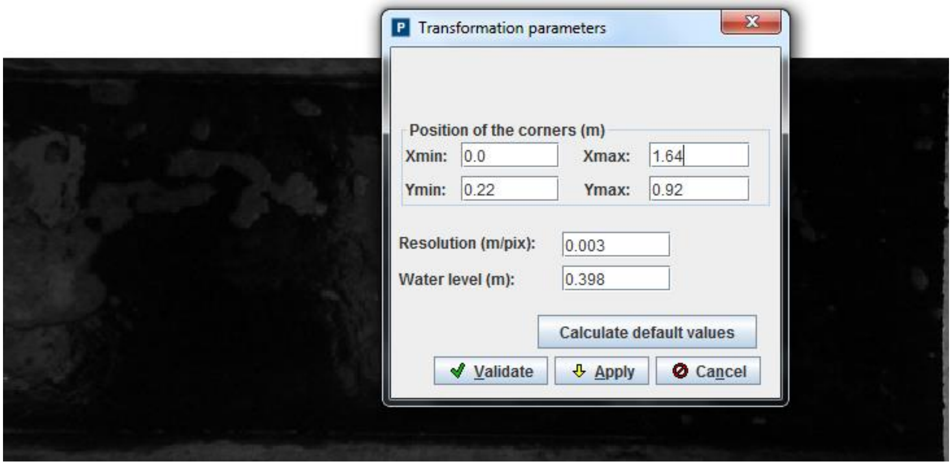
Real X: 0.0
Real Y: 0.0
Real Z: 0.0

Coordinates

	I	J	Real X	Real Y	Real Z
1	142.1	67.48	0.0	0.0	1.291
2	132.79	1084.33	0.0	1.1	1.291
3	989.09	65.15	1.1	0.0	1.291
4	1003.05	1019.17	1.0	1.1	1.291
5	588.86	67.48	0.5	0.0	1.291
6	607.48	1051.75	0.5	1.1	1.291

Figure 25. Fudaa-LSPIV reference points

In the followings, the transformation parameters were added (Figure 26), such as the image resolution, the water level and the X, Y coordinates of the corners of the image section what is actually needed for the velocity analysis. Each one of the 450 images was transformed with these settings and so the image orthorectification could be done.



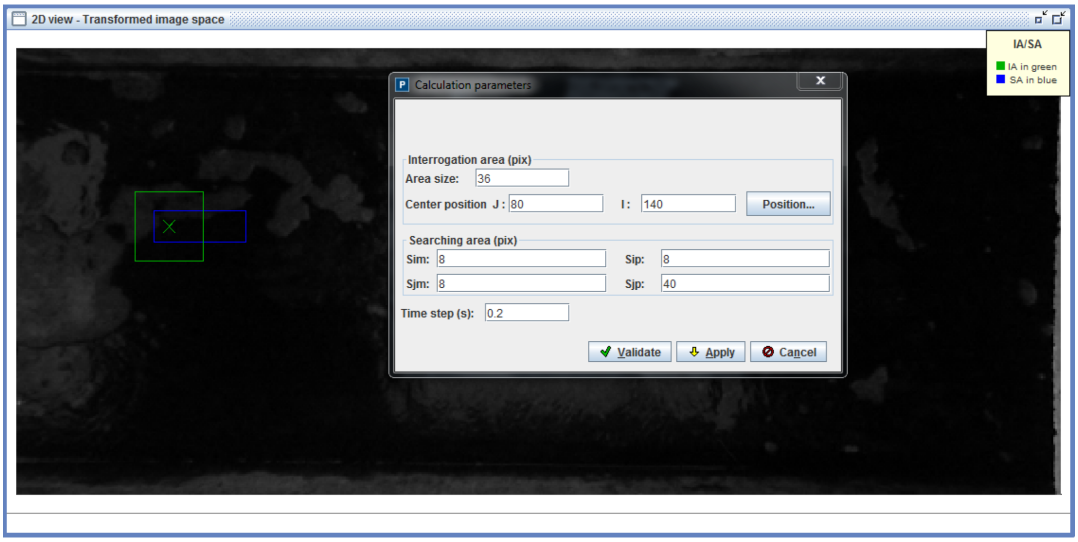
Transformation parameters

Position of the corners (m)
Xmin: 0.0 Xmax: 1.64
Ymin: 0.22 Ymax: 0.92

Resolution (m/pix): 0.003
Water level (m): 0.398

Figure 26. Fudaa-LSPIV image transformation settings

Once the image transformation was successfully performed the next was to carry out the PIV calculation on the transformed images, as was described previously. The PIV parameters were defined (Figure 27), such as the appropriate interrogation area (IA) size, the searching area (SA) size and the time step (dt). The latter could simply calculated based on the time resolution of the images, i.e. in case of 5 fps the dt equals 0.2 s.



Interrogation area (pix)
Area size: 36
Center position J : 80 I : 140

Searching area (pix)
Sim: 8 Sip: 8
Sjm: 8 Sjp: 40

Time step (s): 0.2

Figure 27. Fudaa-LSPIV PIV calculation settings

The velocity vectors will be calculated on a pre-defined grid, which had to be defined in the next step. Also, a filtering of the processed velocities is needed for which information has to be given for the software. Therefore, the minimum and maximum values of the reasonable velocity as well as the cross-correlation coefficient were defined. In the given case, the velocity range was defined between 0 and 0.3 m/s and the minimum correlation of 0.5. The applied correlation coefficient seemed to be pretty low, but due to complex illumination conditions, i.e. there are sunny and shady parts in the measured section, the test justified this setting. After all the settings for the image processing were given, the time-averaged velocity field for the 1.5 min long videos could be assessed (see an example in Figure 28). All the values of the X, Y components of the velocity vectors, i.e. *U* and *V*, are stored in a document. The index velocities, which will actually be used for discharge estimation is calculated as the spatial average of the time-averaged streamwise velocities, i.e. the index velocity is one single velocity (temporally and spatially averaged) data for a given flow situation.

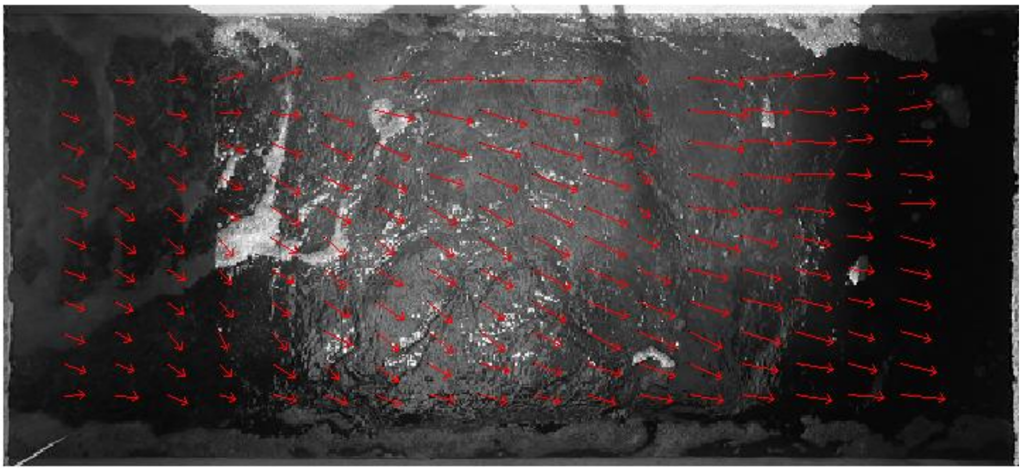


Figure 28. Time-averaged velocity distribution calculated by the Fudaa-LSPIV

4.1.4 Sensitivity analysis

As one of the most important tasks of this study a thorough sensitivity analysis was carried out for the relevant parameters within the LSPIV process. It is crucial to find the right settings to get the most accurate results possible. The time-averaged velocity fields and the calculated index velocity values were compared to each other at different settings. The following parameters were tested:

- image resolution,
- the interrogation area (IA) size,
- the correlation filter,
- necessary length of video.

For the sensitivity analysis a video for one given flow condition was chosen, which was representative for the study case.

As to the different image resolutions (using pixel size values of 2 mm, 3 mm and 6 mm, respectively) no significant changes could be shown, neither for the index velocity (Figure 29) nor for the velocity fields (Figure 30). To understand the importance of this result it is important to note that the lower pixel size we use, i.e. higher image resolution, the higher computational demand we face with. On the other hand, higher pixel size than 6 mm could not realistically describe the patterns due to the sizes of the foams. According to this test choosing too high resolution (low pixel size) is not necessary at all.

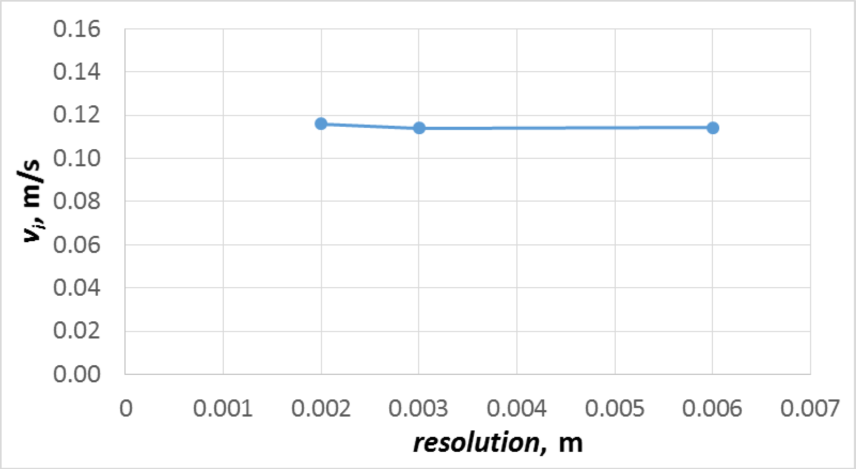


Figure 29. Sensitivity of the index velocity value to the image resolution

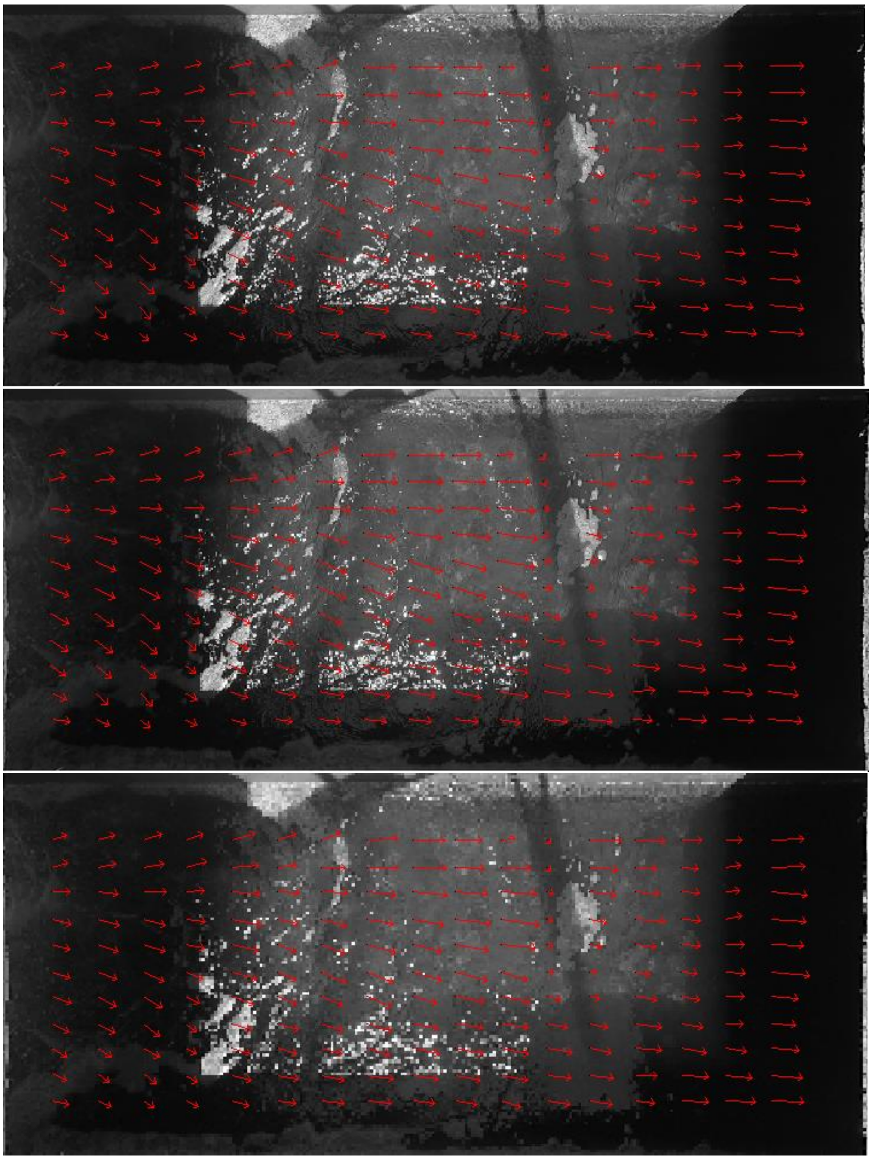


Figure 30. Sensitivity of the velocity field to the image resolution (from top to bottom, 2 mm, 3 mm, 6 mm)

To choose the most suitable size of the interrogation area is more challenging. It has to be large enough to have clearly identifiable patterns within the IA, but on the other hand too large IA makes the processing very long, moreover, will not find velocities close to the edges of the images (see Figure 33). Nevertheless, the analysis showed low sensitivity to this parameter (Figure 32) suggesting the use of low IA size, 36 pixels in this case.

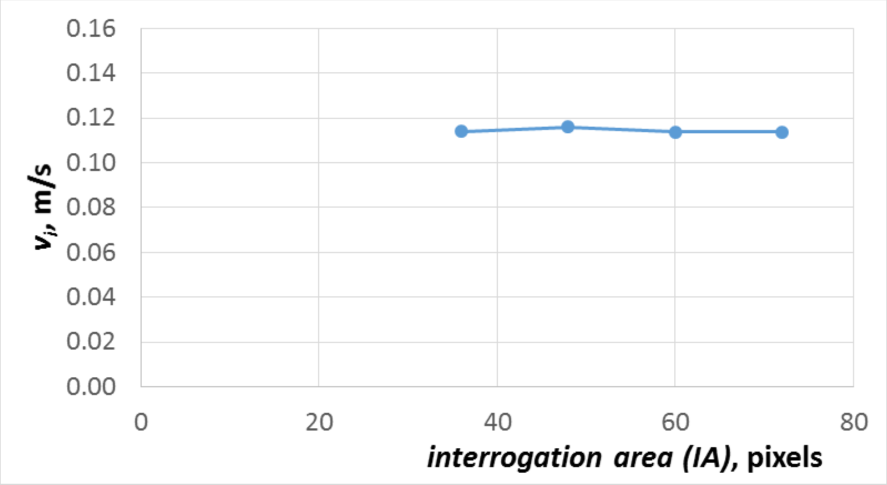


Figure 32. Sensitivity of the index velocity value to the interrogation area size

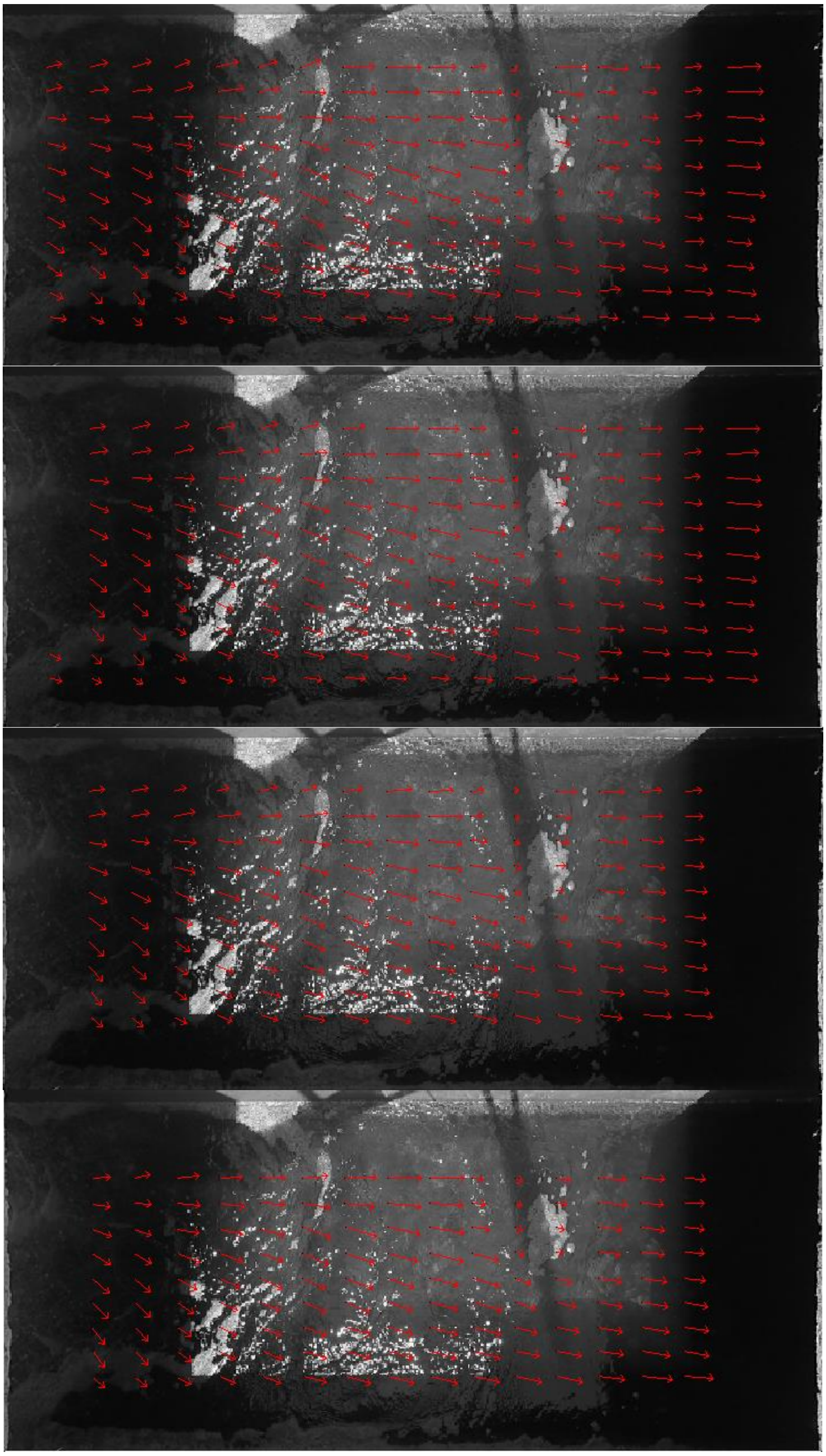


Figure 33. Sensitivity of the velocity field to the interrogation area size (from top to bottom, IA = 36, 48, 60, 72, respectively)

The filter based on the correlation coefficient is used to filter out velocity vectors that were found with low coefficient value. Due to the processing method which is based on a cross-correlation technique (described above) there will always be vectors found for each grid point. However, some of them can be characterized with low correlation coefficient for several reasons, e.g. there was no tracer on the free surface, strong eddies exploded the patterns, the sunlight affected the image, etc. That was, however, a question what the applicable threshold value for this parameter is to have adequate velocity distribution at the end. Too high correlation coefficient (meaning that images with almost the same foam patterns will be used only for velocity calculation) limit cannot be used due the significant difference between the sunny and shady parts of the images, but lowering this threshold value the sensitivity becomes negligible as Figure 34 and 35 show.

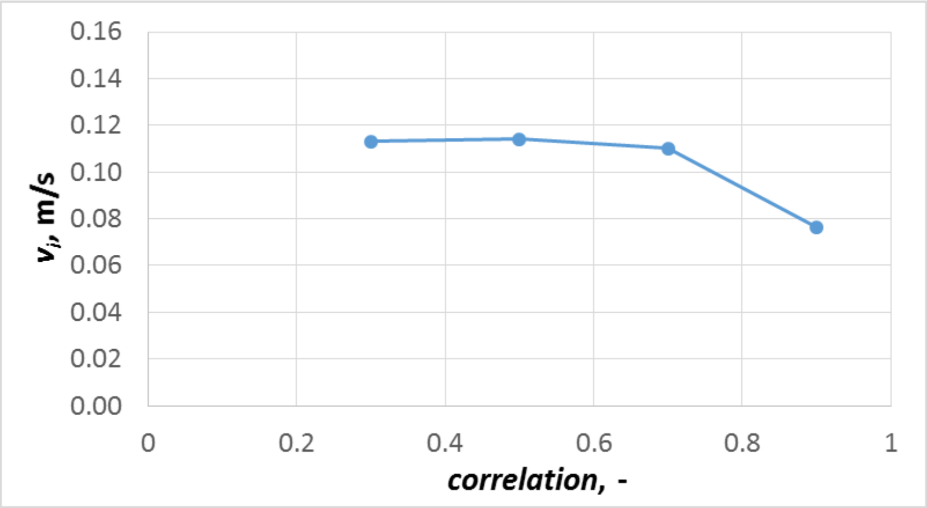


Figure 34. Sensitivity of the index velocity value to the correlation coefficient threshold

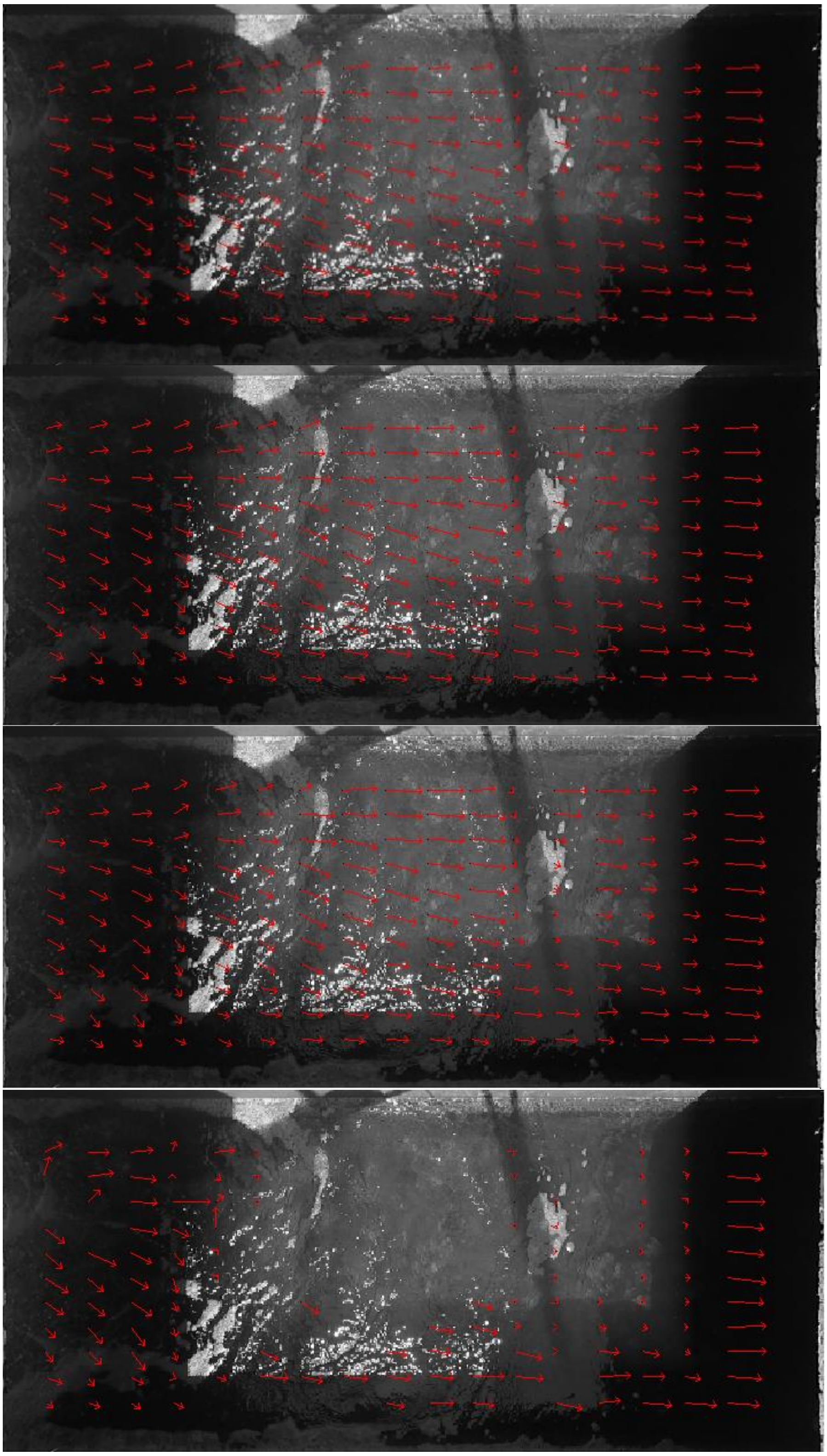


Figure 35. Sensitivity of the velocity field to the correlation coefficient threshold (from top to bottom R = 0.3, 0.5, 0.7, 0.9, respectively)

To see how long videos are needed to find a reasonable index velocity the originally 90 second long video was cut into three parts, having 30 s, 60 s and 90 s long videos. The calculated index velocity values show slight differences only meaning that within the tested ranges the method is not sensitive to the length of the video (Figure 36). Obviously, shorter videos are preferred because they require shorter processing time.

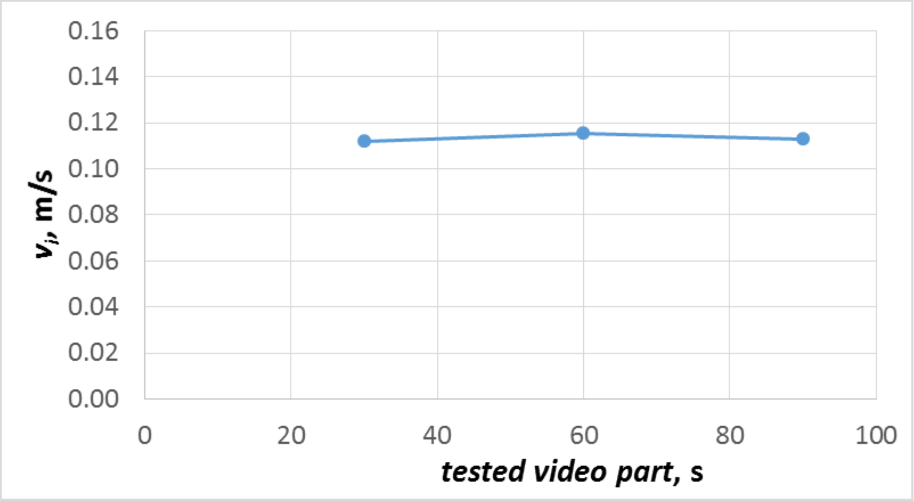


Figure 36. Sensitivity of the index velocity value to the length of the video

4.1.5 Results

Based on the sensitivity analysis, the following settings were chosen for the LSPIV procedure:

- pixel size = 0.003 m
- IA = 36 pixel
- correlation coefficient threshold, R = 0.5
- length of the processed video, T = 90 s

All the videos were processed using the above settings and the relationship between the index velocity (from LSPIV) and the cross-section averaged velocity (from ADV) was established (Figure 37, Table 2).

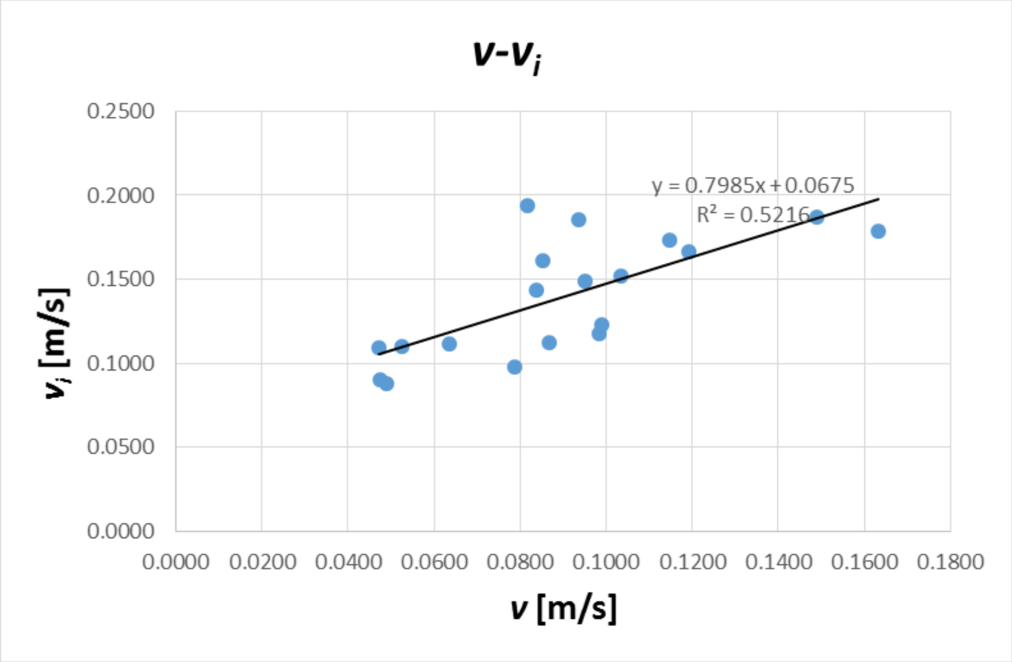


Figure 37. The calculated average velocity and index velocity relationship

Number of measurement	*h*[m]	*B* [m]	v_{av} [m/s]	v_i [m/s]	*Q* [m^3/s]	*Q* [m^3/h]
1	0.398	1.1	**0.0490**	**0.0875**	0.0215	77
2	0.398	1.1	**0.0472**	**0.1095**	0.0206	74
3	0.348	1.1	**0.0525**	**0.1097**	0.0201	72
4	0.347	1.1	**0.0636**	**0.1113**	0.0243	87
5	0.42	1.1	**0.0474**	**0.0898**	0.0219	79
6	0.384	1.1	**0.0789**	**0.0979**	0.0333	120
7	0.58	1.1	**0.0837**	**0.1436**	0.0534	192
8	0.543	1.1	**0.0989**	**0.1227**	0.0591	213
9	0.595	1.1	**0.0983**	**0.1176**	0.0643	232
10	0.595	1.1	**0.0951**	**0.1487**	0.0622	224
11	0.556	1.1	**0.1035**	**0.1516**	0.0633	228
12	0.625	1.1	**0.1148**	**0.1729**	0.0789	284
13	0.645	1.1	**0.0936**	**0.1856**	0.0664	239
14	0.579	1.1	**0.1193**	**0.1667**	0.0760	274
15	0.609	1.1	**0.1632**	**0.1783**	0.1093	394
16	0.693	1.1	**0.0816**	**0.1942**	0.0622	224
17	0.663	1.1	**0.1489**	**0.1870**	0.1086	391
18	0.592	1.1	**0.0854**	**0.1614**	0.0556	200
19	0.634	1.1	**0.0867**	**0.1121**	0.0605	218

Table 2. The calculated average velocity and the index velocity values

As already noted at the stage-discharge curve, at this plot again one can observe a certain scattering of the data, however, based on the regression line the expected behavior can be seen showing higher velocities at the free surface than overall in the cross section.

This is due to the logarithmic shape of the velocity distribution both in the transversal and the vertical direction (see again Figure 13). The scattering is most likely caused by the dynamic behavior of the flows in the treatment plant. During the ADV measurements, which needed 10-14 minutes, the water level could easily increase or decrease with 50% representing different discharge in the beginning and in the end of velocity measurement. To overcome this issue a much faster concurrent discharge measurement method would be suitable which can follow the dynamic “floods”, e.g. the calibrated Parshall-flume, or even an acoustic Doppler current profiler (ADCP).

5 Implementation of LSPIV based discharge measurement for a natural stream

5.1 Study site

The measurements took place in a section of the stream Által-ér in Tata between September and October 2015 (Figure 38). The study section of Által-ér usually has low water from November until September and high water in October when the water level of lake Tatai (Öreg)-tó, which is located upstream of the site, is artificially decreased for the winter period. Five measurements were carried out during the above indicated period at somewhat different flow conditions. The reasons to choose this site for this study were the followings:

- there is an official gauge of the North-Transdanubian Water Directorate nearby where continuous (every 1 hour) water level registration is done
- stage-discharge relationship is available for the gauge, which can be used to check the measured discharge values
- a manmade weir right upstream of the site ensures “natural” tracers, foam, on the free surface permanently
- the location is suitable to deploy video camera and all the required infrastructure
- the site is easily reachable by car and is in a driving distance from BME

Figure 38. Measurement location at the stream Által-ér in Tata

5.2 Measurement methods

The free surface of the water was recorded with the *GoPro* action camera, the same as used at the previous study site, which was mounted on a 3 meter tall stand. The measurement setup is introduced in Figure 39, indicating the video camera, the measured area of the stream and the reference points used for the orthorectification.

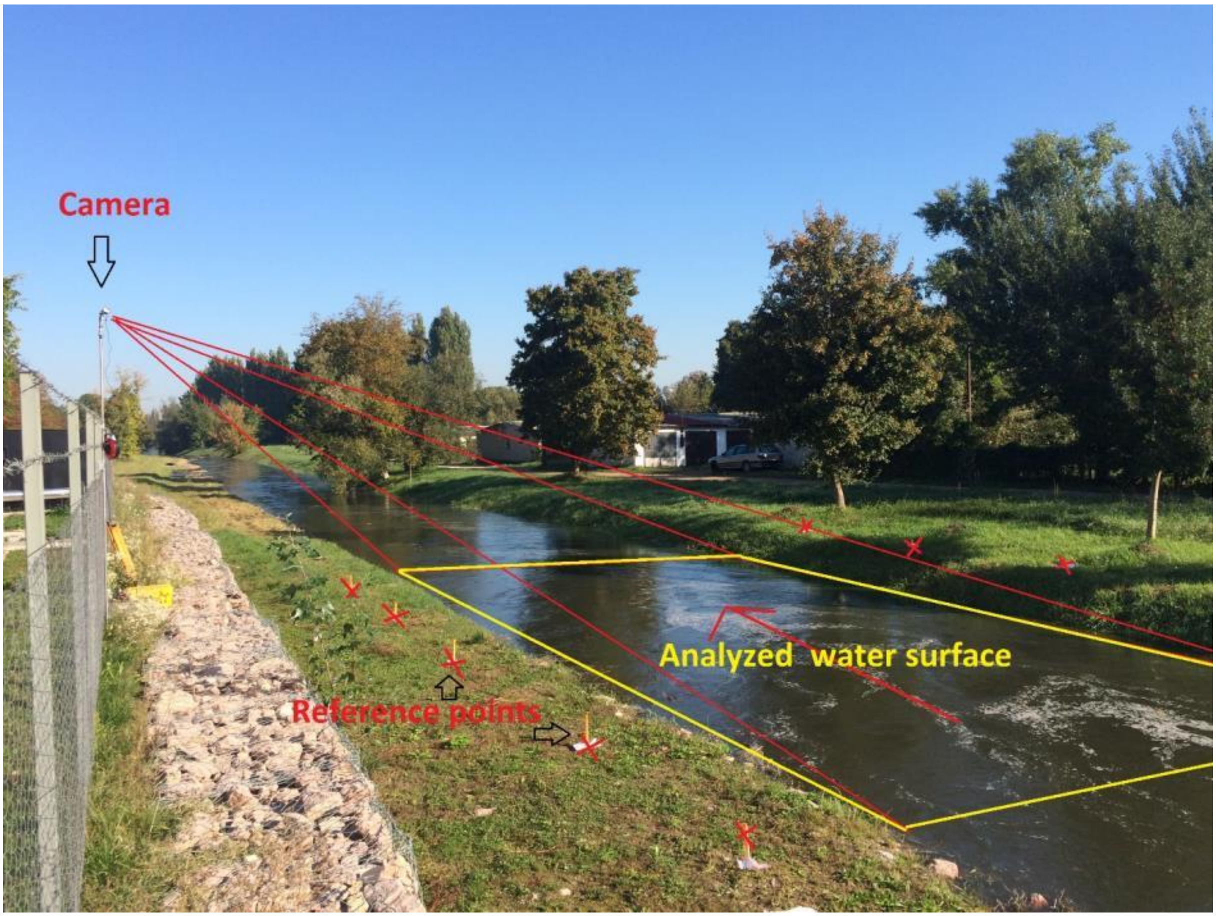


Figure 39. The study site and the measurement setup at Által-ér

10 ground reference points (GRPs) were defined. Their X, Y and Z coordinates were measured with an RTK (Real Time Kinematic) GPS thus the absolute positions of the reference points could be documented. As one of the goals was to establish a relationship between the index velocity (i.e. a characteristic velocity on the free surface) and the cross-section averaged velocity (for estimating the discharge at known wetted areas) besides the video recording concurrent discharge measurements were performed. As a suitable reference for the measured discharges the already available stage-discharge relationship for the nearby gauge was used (Figure 40). The flow discharge was measured with an ADCP (Figure 41).

Figure 40. Low water and high water gauge

Figure 41. ADCP measurement

The ADCP instrument was mounted on a trimaran and was pulled throughout the study cross section by two people using a cord. As conventionally, several repeated measurements were conducted (at least 10 times) to acquire a reliable discharge value. As an additional information, the measurement software provided the size of the wetted area as well, which was needed to find the relationship between the water level and the cross-section area.

In this study the goal was two-fold:

1. To establish a relationship between:
   a. index velocity (v_i) and cross-section averaged velocity (v)
   b. water level (at the gauge) and the wetted area (H-Q)
   c. using the first two equations, to find the relationship between the index-velocity and the flow discharge, v_i-Q (the latter calculated by $Q = A \cdot v$)
2. To setup an online LSPIV based measurement system which could be used to monitor the flow discharge continuously based on video camera recordings

5.3 Relationship between the index-velocity and flow discharge (Goal 1)

During this stage of the study five measurement campaigns were carried out at the Által-ér site. This meant five days of measurement at different flow conditions of the stream (i.e. different water levels discharges). Table 3 shows the dates of the measurements, the detected water levels at the gauge and the measured flow discharges, respectively.

Date	***H* [cm]**	***Q* [m³/s]**
9.23.2015	27	0.214
10.30.2015	59	1.900
10.07.2015.	61	2.290
10.21.2015.	63	2.690
2015.10.02	99	7.450

Table 3. The dates of the measurements, the detected water levels at the gauge and the measured flow discharges

A preliminary sensitivity analysis showed similar results compared to the ones introduced in the previous point. The optimal image resolution was found to be 3 mm. The optimal size of the interrogation area (IA) still depends on the sizes of the moving foams on the free surface. In this case, using 3 mm pixel size and the typically smaller size foams, an IA size of 60 is recommended. The sensitivity to the correlation coefficient threshold values is also the same here thus a value of 0.5 is recommended. As a significant difference to the previous case study there are no very dynamic changes in the flow conditions which would make the velocity measurements uncertain. This also means that it would not be necessary to process long videos. On the other hand, due to the lower number of tracers on the surface the videos need to be long enough to make sure that there are foams throughout the whole section during the video recording.

Using the above described settings for the LSPIV the index velocities (i.e. the time and spatially averaged free surface velocity) were processed from the video recordings. As mentioned above, the discharge and wetted area values for each measurement were available from the ADCP surveys. Based on this the cross-sectional averaged velocities for each measurement campaign could be calculated as $v = Q / A$ and thus the relationship between the index velocity and the cross-sectional averaged velocity could be established (see Figure 42 and Table 4). Although only five value pairs could be assessed, the relationship is clearly strong and justifies the expected behavior that the free surface velocities are always higher than the section-averaged ones.

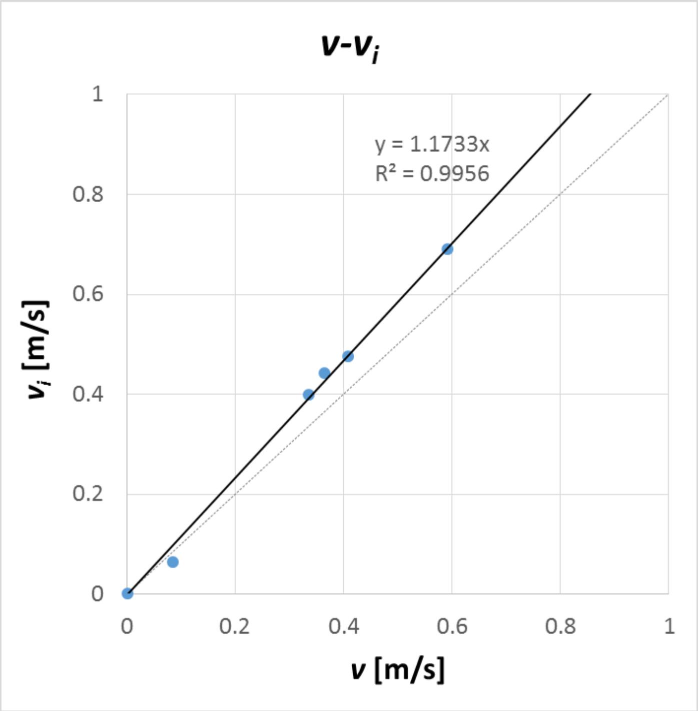


Figure 42. The established v-v_i relationship for the study section of Által-ér

v [m/s]	**v_i [m/s]**
0.086	0.065
0.336	0.399
0.365	0.443
0.408	0.475
0.591	0.690

Table 4. The v-v_i relationship for the study section of Által-ér

As the second step for the discharge estimation it was important to develop a relationship between the detected water level at the gauge (*H*) and the wetted area of the study section (*A*). This relationship between, where the wetted area was provided by the ADCP data, is plotted in Figure 43 (and Table 5). Again, although the number of the available data was fairly low the relationship could be described with a polynomial regression with high regression coefficient.

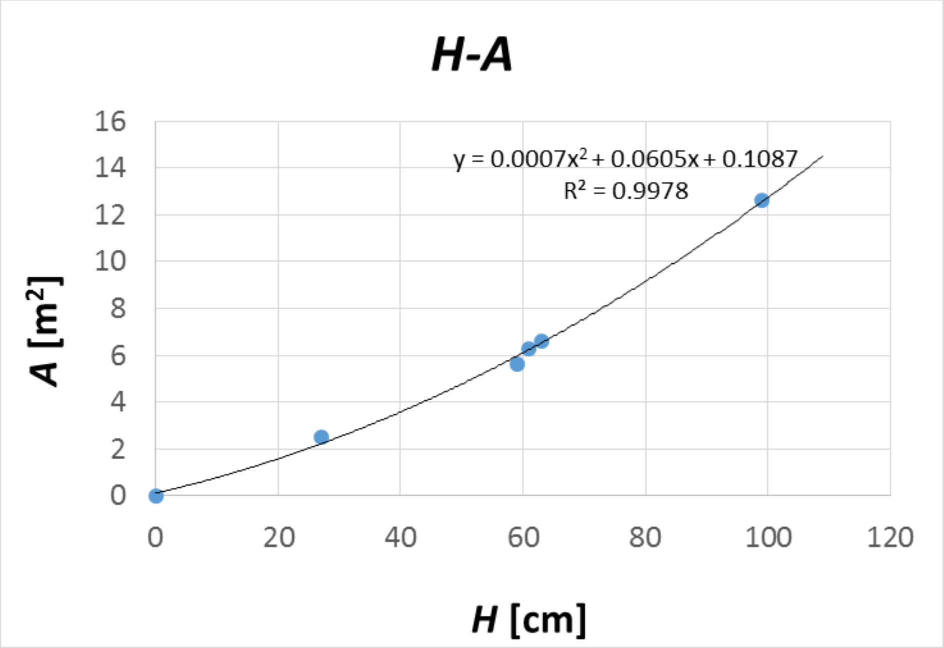


Figure 43. Relationship between the water level at the gauge and the wetted area of the study section

***H* [cm]**	***A* [m^2]**
27	2.500
59	5.650
61	6.280
63	6.590
99	12.600

Table 5. Relationship between the water level at the gauge and the wetted area of the study section

Using the established equations for the v-v_i and for the H-A relationships the estimation of the flow discharge from parallel LSPIV measurements and water level detection can be performed using the following formula:

$$Q = A \cdot v = (0.0007H^2 + 0.0605H + 0.1087) \cdot (1 / (1.1733 \cdot v_i)) \text{ (note that } H \text{ is in cm)}$$

Since the water level is automatically recorded (and published online) hourly by the water directorate, if we can manage to provide continuous index velocity data by the LSPIV method, the discharge of the stream could be continuously estimated. Therefore, in the following point we make an attempt on setting up an online velocity measurement system using the LSPIV method.

5.4 Setup of an online velocity measurement system (Goal 2)

At this point of the study a new device was applied to record video of the water surface. A so called IP camera (introduced later) will be used which is able to send the information online, but also the image processing method had to be automatized in order to have a robust system avoiding manual steps.

5.4.1 Automatized LSPIV procedure

The main goal was to avoid the previously used Java based FUDAA-LSPIV software for the image processing, since it needs a large amount of manual settings and cannot be automatized within the software.. However, the software developers provided the executables of the subroutines (a list of exe files) responsible for the specific steps of the image processing procedure. A new application has been developed in C++ environment which actually puts together these executables and is able to manage a large amount of images, moreover, it provides pre-processing (such as video-image conversion) and post-processing (discharge calculation) which is needed to have a completely automatized system. This frame program, called *'LSPIVfr.*exe', needs input files with all the settings that are necessary for the LSPIV calculations (e.g. image resolution, delta time between images, sizes of IA and SA, location of the calculation grid, water level, etc.). Besides the input files the program needs one video file, consisting the recording of the water surface, and one more parameter, the angle of the flow for the calculation of the streamwise velocity components. Once all these information are correctly defined the program can be started from the command line and will create images from the video, transform all the images, perform the PIV calculations, calculates the index velocity and estimates the discharge based on the pre-defined formula (see above). The structure of the program is introduced in Figure 44.

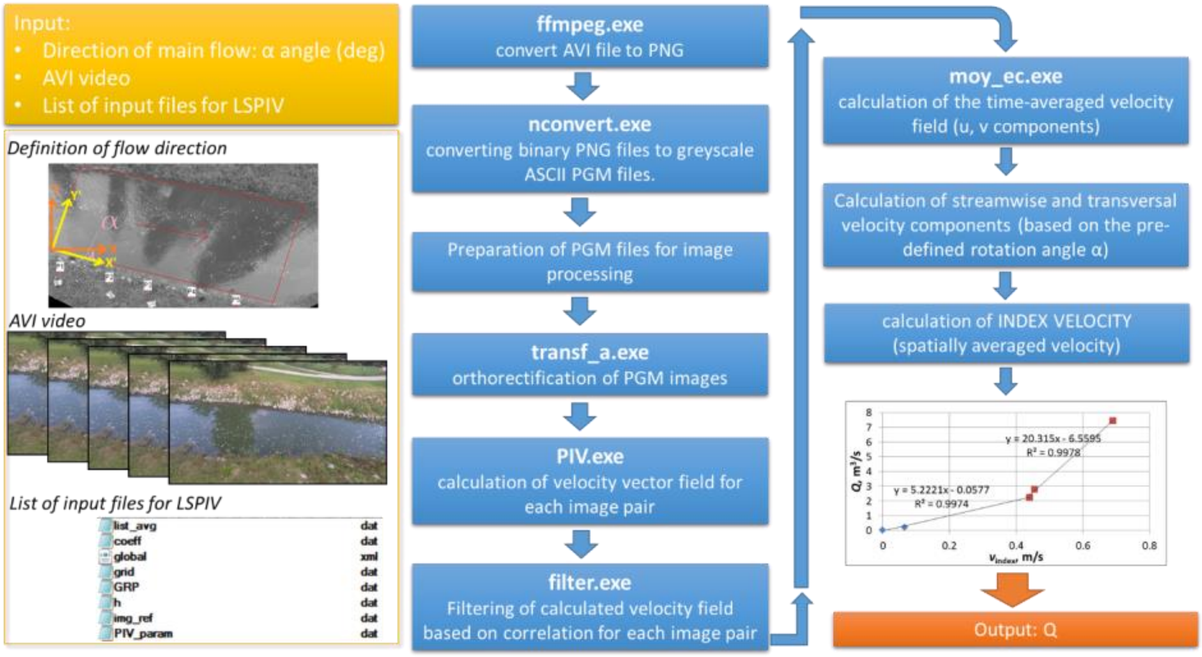


Figure 44. Structure of the LSPIVfr.exe frame program for automatized discharge estimation

5.4.2 Setup of the online measurement system

In order to have a permanents discharge measurement system, the applied video camera needs power supply, internet connection as well as a stable and secure place to mount. During this study the video camera was fixed to a tall enough stand, as it was obviously not a realistic goal to setup a permanent station. The goal, however, was to introduce the applicability of such a system.

A *Foscam* FI9903P IP camera was used (Shenzhen Foscam Intelligent Technology Co.) to test the online system (Figure 45). The resolution of the video camera can be full HD, however, the applicable resolution, in fact, depends on the strength of the available internet connection. The live view is available through a P2P mobile network via the freely available *Foscam Client* software. To create the direct P2P connection between the IP camera and the application, a router and a 4G GSM stick had to be deployed. To ensure the power supply, there was a battery available complemented by an inverter and power strip for the IP camera and the router. The structure of the developed system is shown in Figure 46 and 47.

Figure 45. Foscam FI9903P IP camera [source: www.onlinecamera.net]

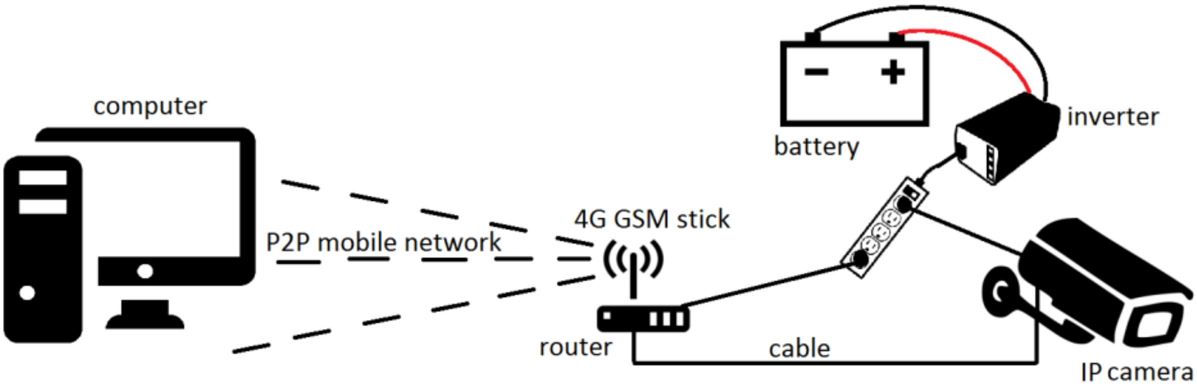


Figure 46. The structure of the online discharge measurement system

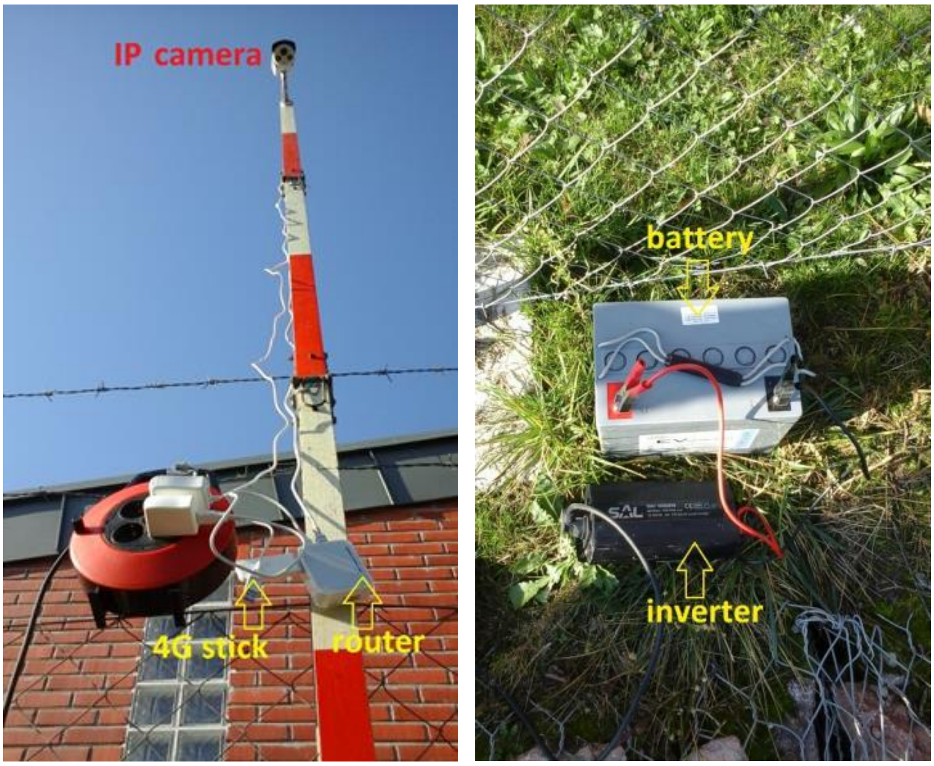
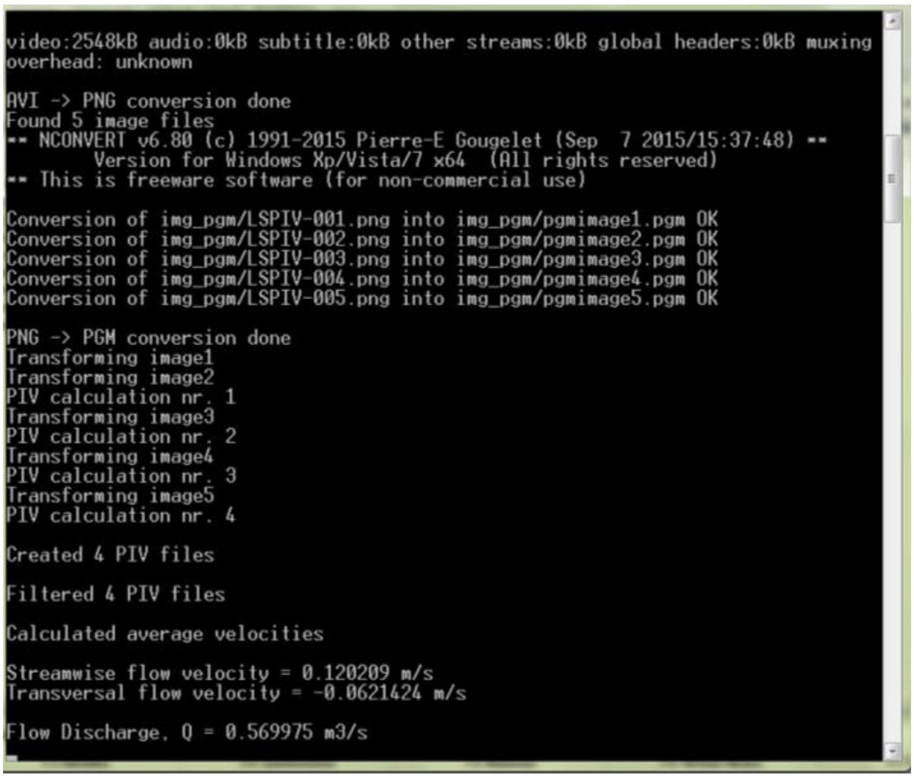


Figure 47. The measurement configuration at the study site

The quality of the video is adjustable with the *Foscam Client* software but the number of frames per second of the video depends on the signal strength of the 4G so with higher quality the number of fps may be lower than what is necessary for the suitable LSPIV process. The field testing showed that this system works fairly well with wireless internet connection. The LSPIV processing works with low and medium quality videos also very well as the moving foams on this lower resolution images are still well recognizable. On the other hand, using high quality videos the time resolution of the videos will be low and thus the image processing will not provide reliable estimations. Certainly, if cable internet connection is available, no such issues arise and both high image and time resolution can be ensured. With the established online system we are able to collect real time video recordings on any host computer and having the above described input information for the LSPIV procedure the LSPIVfr.exe program immediately calculates the flow discharge (see an example of the program running in Figure 48). Due to the high relatively high computational demand of the PIV calculations the processing is somewhat slower than the real time. It means that for instance, a one minute long video recording can be processed in circa 20 minutes and so this is the delay of the discharge estimation compared to real time. We believe that this sort of time delay is negligible.



```
video:2548kB audio:0kB subtitle:0kB other streams:0kB global headers:0kB muxing
overhead: unknown

AVI -> PNG conversion done
Found 5 image files
** NCONVERT v6.80 (c) 1991-2015 Pierre-E Gougelet (Sep  7 2015/15:37:48) **
        Version for Windows Xp/Vista/7 x64  (All rights reserved)
** This is freeware software (for non-commercial use)

Conversion of img_pgm/LSPIV-001.png into img_pgm/pgmimage1.pgm OK
Conversion of img_pgm/LSPIV-002.png into img_pgm/pgmimage2.pgm OK
Conversion of img_pgm/LSPIV-003.png into img_pgm/pgmimage3.pgm OK
Conversion of img_pgm/LSPIV-004.png into img_pgm/pgmimage4.pgm OK
Conversion of img_pgm/LSPIV-005.png into img_pgm/pgmimage5.pgm OK

PNG -> PGM conversion done
Transforming image1
Transforming image2
PIV calculation nr. 1
Transforming image3
PIV calculation nr. 2
Transforming image4
PIV calculation nr. 3
Transforming image5
PIV calculation nr. 4

Created 4 PIV files

Filtered 4 PIV files

Calculated average velocities

Streamwise flow velocity = 0.120209 m/s
Transversal flow velocity = -0.0621424 m/s

Flow Discharge. Q = 0.569975 m3/s
```

Figure 48. Screenshot taken during the LSPIV processing using the LSPIVfr.exe program

6 Discussion

Detailed testing and a novel implementation of a video based discharge estimation method were carried out in this study. The results in overall clearly suggest the potential of this indirect measurement technique, however, the study pointed out several complex aspects of the methodology. It was shown that the LSPIV method works reliably and stable when there are proper tracers on the water surface. This element of the method is basically the most important one as the method simply does not work if there are no visible patterns on the surface to track. There are other important conditions to ensure good quality measurements, such as having quasi-steady flow during the surveys especially when conducting the calibration measurements. It is also important that the measurement section is well-defined and can be detected with a video camera, i.e. even during flood situation the flow remains in the channel. A pre-requisite of the method is to have available water level information in the time of the video recordings.

The sensitivity analysis, carried out in Chapter 4, pointed out the method is in fact, quite robust and there are only a few parameters which have to be chosen carefully. Such a feature is the threshold correlation coefficient used for filtering the calculated velocity field. It was also shown that the sizes of the interrogation and search area can be quite well estimated based on the image resolution and the typical flow velocity which can be estimated by eye (just to have an order of magnitude guess). As to the time resolution it was shown that within the measured velocity ranges, 0-1 m/s, a value between 3 or 5 frames per second is suitable.

It is important to note that this is an indirect flow measurement technique and therefore needs calibration. The proper implementation of the calibration measurements is essential. In this study the ADV measurements were too time-consuming at the very dynamic flow conditions of the wastewater treatment plant but on the other hand the acoustic measurements at the Által-ér were well applicable.

The applied image processing software, the *Fudaa-LSPIV* is well-suited for sensitivity analysis but its disadvantage that it cannot be automatized and therefore it is not useful for the permanent discharge estimation. On the other hand, the program developed in this study, which uses a series of several subroutines, and can be run from the command line is capable to automatically perform all the processes for the discharge estimation and can be linked to an online video system to provide real time discharge information.

7 Conclusions

This herein presented system can be applied to any streams where the introduced conditions can be ensured, such as the tracers on the water surface or the thorough preliminary calibration procedure.

It is important to note that the parameters used in the LSPIV methodology were not significantly sensitive, but it can be different at different flow conditions and so such an analysis is vital to be performed in other cases. The GoPro action camera was suitable for testing purposes but an IP camera has much better capabilities in the longer term for automatizes measurements and also it is more cost-effective. Furthermore, for continuous measurements the necessary infrastructure needs to be provided like the power supply, internet connection and the security. In case of a real application of the method it is recommended to reveal the possible changes of the geometry of the study section as it affects the calibration.

This study clearly demonstrates the capabilities of the video based discharge estimation methodology, moreover, we provide a well-tested tool as well, which can be implemented in the future operation of the water directorates. Due to the indirect manner of the measurements this technique can be a good alternative or even the only one in cases where no direct discharge measurements can be performed, especially during flash floods and at locations where the conventional methods face difficulties.

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