INTERPRAEVENT
2021 – Norway

14th Congress INTERPRAEVENT 2021
Norway – Paper
www.interpraevent.at

Image-based flow measurements in wide rivers using a multi-view approach

Salvador Peña-Haro[1], Robert Lukes[2], Maxence Carrel[3], Beat Lüthi[4]

Keywords: Discharge, Wide rivers, Cameras, SSIV

Abstract

A multi-view image based system has been developed to measure the discharge in large rivers using Surface Structure Image Velocimetry. In large rivers the image resolution might not be enough to allow for a proper characterization of the flow surface patterns. To get more detailed surface patterns, a Pan-Tilt-Zoom camera was used, which has the capability to move and zoom into smaller areas of the river on the spannwise direction. The system has been installed in the Zollbrücke on the Rhine river where it is around 100 meters wide during low flow conditions. The system records videos with a duration of 5 seconds in each one of the views every 5 minutes. One month of data was compared against the reference values. The mean discharge during that period was of 190 m^3/s and the Root Mean Square Error was found to be 8.4 m^3/s compared to the official values.

Introduction

Knowing the volumetric flow in rivers is essential to analyze hydrological process, and for many applications ranging from flood forecasting to water resources management. And at the same time it is one of the most difficult variables to measure. Discharge is normally estimated by using stage-discharge curves which are established by having some measured discharges at different stages and then a curve is fitted to those measured values. Latter on, only river stage is continuously measured, for instance with pneumatic gauges (Creutin at al., 2003, Turnipseed and Sauer, 2010).

During the last years several image based methods for measuring the surface velocity in rivers and channels have being proposed (Fujita et al., 2007, Patalano, et al., 2017, Jodeau et al., 2017, Leitão et al., 2018, Tauro et al., 2018). Image based discharge measurements posses several advantages, one of them being that the sensor (camera) is not in contact with the water and its mounting position is very flexible and there is no need of expensive structures to mount it. Beside environmental factors, the performance of image based discharge measurements depends on the image resolution. In large rivers the image resolution at the far field can be very poor (Muste et al., 2011). To overcome this problem we used pan-tilt-zoom (PTZ) cameras which are capable of moving and zooming.

[1] Photrack AG, Switzerland, (pena@photrack.ch)
[2] Swiss Federal Office for the Environment, Switzerland
[3] Photrack AG, Switzerland
[4] Photrack AG, Switzerland

Herein we present a new implementation of an image based discharge measurement using PTZ cameras, this feature allows to look at a smaller parts of the river by zooming in. Several videos are recorded and processed individually to obtain the surface velocity. Later the calculated surface velocities of each of the views are assembled and the discharge is computed.

Methods

Traditional camera calibration in Large Scale Image Velocimetry (LSPIV) methods require to have visible Ground Control Points (GCP) on the river shores (Creutin et al, 2003, Kim et al., 2006, Jodeau et al, 2008) which should be visible on the image. When measuring the discharge in large rivers using a PTZ camera, it can be zoomed into smaller parts of the river. By doing this, it can happen that a camera view would only contain water with no visible shores, hence we developed a new camera calibration methodology which does not need to have any visible GCP on the image which is going to be processed.

From PTZ cameras it is possible to extract information related to the pan and tilt angles as well as the zoom factor. The PTZ camera calibration consisted on finding the camera mount orientation and on establishing a relation between the zoom factor and focal length of the camera. To do this, GCP have to be placed in any place which is visible to the camera and the pan/tilt values of the camera have to be read for each of the GCPs. This information was used to estimate the camera mount once this is known, it is possible to move the camera to any location with any zoom level and calculate the world coordinates of a given pixel of the view (for a given water level).

After camera calibration, the discharge is calculated as follows. The water level is measured optically by segmentation of images of a view located on the right shore of the river (see Figure 2 A). The surface velocity measurements are obtained by applying the Surface Structure Image Velocimetry (SSIV) method (Leitão et al., 2018) to the recordings of the remaining views, yielding a surface velocity field spanning over the entire width of the river. It is assumed that the cross-section of the river remains constant for the portion considered. A fit is applied to the stream-wise components of the surface velocity yielding a surface velocity profile. The fit is done using a least square regression with a model function which depends on the cross section.

The average vertical velocity for discrete sections over the width of the river is obtained by applying the ISO norm 748:2007, which is a standard expressing the average velocity of a river section as a function of its depth and roughness coefficient. For each discrete section the discharge is calculated by multiplying the average velocity and the area of that section. Finally, the total discharge is then obtained by integrating the discharge of all the discrete sections.

Case study

The measurement system presented in this study is installed on the Zollbrücke on the Rhine river, at the border between Switzerland and Austria. At this location the river width is of approximately 100 meters under low flow conditions, while the width of its floodplain is of about 200 m (Figure 1, left).

At the site there is an official station from the Swiss Federal Office for the Environment (FOEN), where there is a SOMMER RQ-30 radar sensor under the bridge. The river stage and a rating-curve are used to get the reference current discharge.

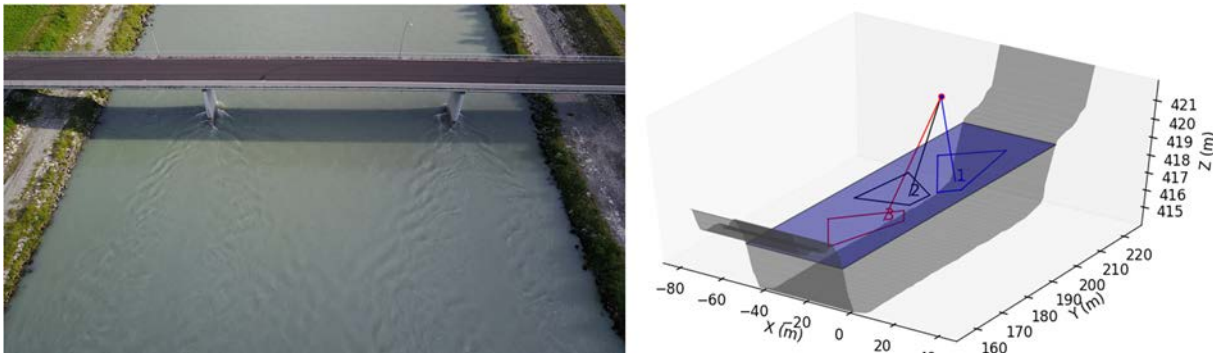

Figure 1 Aerial view of the Rhine river and the bridge where the camera is mounted (left). Camera position and different camera views where the surface velocity measurements are performed (right).

In order to measure the surface velocity field over the whole river width, a PTZ camera was installed (Vivotek SD9364-EH, which also has an integrated IR light), and 3 views were defined in order to cover the whole river width (Figure 1 right). An additional view was defined for the level measurement. The camera records videos of 5 seconds in each one of the views every 5 minutes. The videos are recorded with HD resolution and a frequency of 30 fps.

The system is also running during night, for this end the camera used is equipped with an infrared light whose zoom is synchronized with the one of the camera. Making use of this feature, it is possible to measure optically the water level on the right shore of the river over night (Figure 2A). The infrared projector is too weak to allow to measure the surface velocity fields in all views, therefore during night the surface velocity measurements are performed only in the vicinity of the bridge, close enough to ensure a good infrared illumination.

Results and discussion

Figure 2 shows the results of a single measurement, it comprises the level detection (Figure 2A) and the surface velocity for the 3 views (Figure 2B, 2C and 2D).

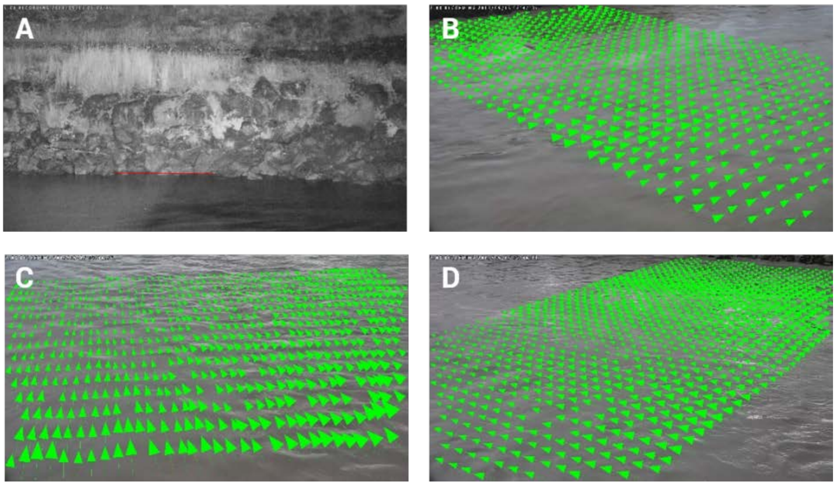

Figure 2 (A) View used for the automatic water level detection (red line). Surface velocity fields measured for the views located on the left (B), middle (C) and right (D) of the river.

After the surface velocities are independently calculated for each view, the measured stream-wise velocity components are assembled and a velocity profile is fit to them over the whole river surface width (Figure 3). Then, for the surface velocities obtained with the fit, an average velocity is calculated using the ISO standard. The discharge is computed by integrating the average velocities and corresponding depths over the entire river width.

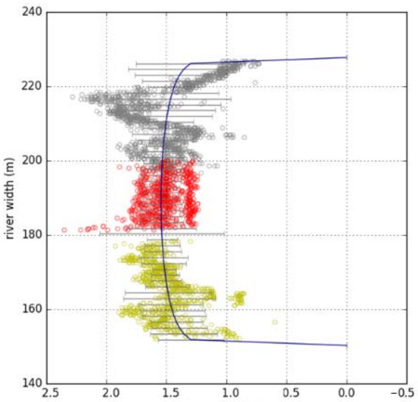

Figure 3 Stream-wise velocity components measured on the left (yellow), middle (red) and right (grey) sides of the river as well as the fit applied to these velocities (blue).

Discharge time series of a month obtained with the camera-based system were compared to the reference values. Figures 4 and 5 show the unfiltered time series of water level and discharge obtained by means of SSIV for a time period between January 10th and February 10th, 2018 with time intervals of 10 minutes. At first glance, the water level and measured discharge with the PTZ camera look fairly similar to the official values. All time series show important daily fluctuations reflecting the effect of the hydro-power facilities located upstream. This is quite interesting for this study because these daily fluctuations mean that the variables measured cover an important range allowing an extensive comparison of both measurement systems.

The root mean square error (RMSE) was used in order to perform a qualitative comparison between the reference data and SSIV. For the water level an RMSE 0.068m was calculated and for the discharge 8.487 m^3/s.

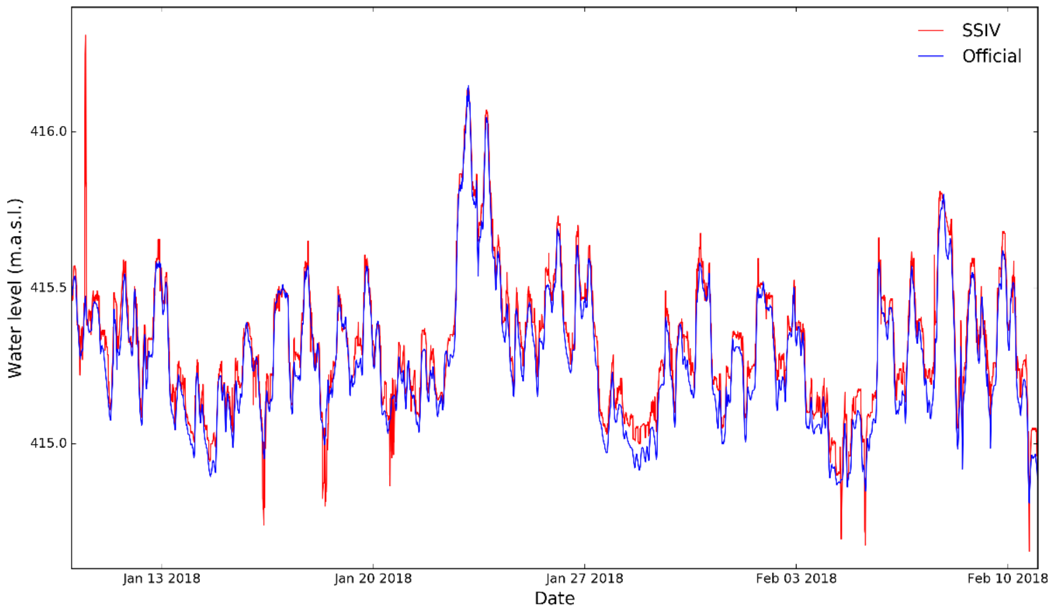

Figure 4 Time series of water level measurements by the camera-based system and the official ones.

The water level expressed as a functions of the discharge is often referred to as rating curves, and for our case it is shown in Figure 6. Also in this graph it can be seen the good agreement between the reference and the measured values.

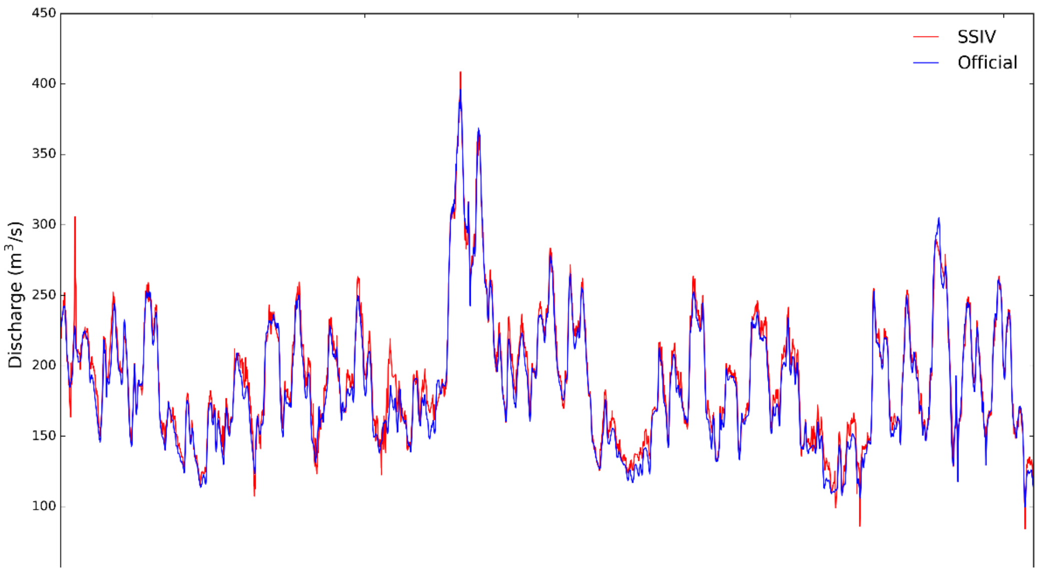

Figure 5 Time series of discharge measurements by the camera-based system and the official ones.

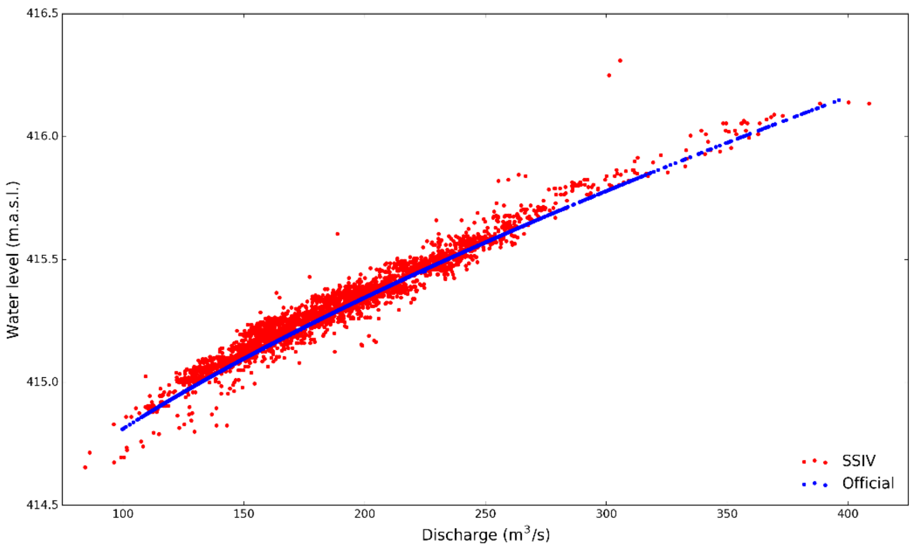

Figure 7 Stage-discharge curve. Red dots are the ones from the SSIV + PTZ camera. Blue dots are the official values.

Within this setup there are some factors than can affect the surface velocity measurement accuracy, like the camera potential to always come back to the same predefined position, and the influence of the bridge vibration on the recorded videos. Regarding the first point, the used camera can pan and tilt with steps of 0.016072 degrees, which allows to accurately go back to the predefined positions. As mentioned before, the camera was mounted under a bridge which is open to vehicles. Therefore the camera is subject to vibrations, however it was observed that the vibrations did not have any visible influence on the surface velocity measurements. This is, the direction and magnitude of the vector are in correspondence with the flow direction. However further research is needed to quantitatively determine the vibration influence on the measured surface velocity.

One interesting feature of the image based methods is that every measurements come with a proof-image so that the plausibility of the results can be checked directly by the operator. Additionally, it is possible to access the measurement system in real-time, or even to take control of the camera and to make use of the PTZ functionality to monitor the surroundings. This is a function that is in particular of interest for locations where natural elements (e.g. floods, landslides, drift wood) potentially can cause important hazards to habitations, bridges, hydraulic structures etc.

Conclusions

This study introduced an image-based measurement system relying on the use of a PTZ camera for performing water level, surface velocity and discharge measurements in a wide river. The mean discharge during that period was of 190 m^3/s and the RMSE was found to be 8.437 m^3/s. The system has proved to perform well and has the potential to measure even wider rivers.

References

Creutin, J. D., M. Muste, A. A. Bradley, S. C. Kim, and A. Kruger. “River Gauging Using PIV Techniques: A Proof of Concept Experiment on the Iowa River.” Journal of Hydrology 277, no. 3–4 (2003): 182–94. https://doi.org/10.1016/S0022-1694(03)00081-7.

Fujita, Ichiro, Hideki Watanabe, and Ryota Tsubaki. “Development of a Non-intrusive and Efficient Flow Monitoring Technique: The Space-time Image Velocimetry (STIV).” International Journal of River Basin Management 5, no. 2 (2007): 105–14. https://doi.org/10.1080/15715124.2007.9635310.

Hauet, Alexandre, Jean-Dominique Creutin, and Philippe Belleudy. “Sensitivity Study of Large-Scale Particle Image Velocimetry Measurement of River Discharge Using Numerical Simulation.” Journal of Hydrology 349, no. 1–2 (2008): 178–90. https://doi.org/10.1016/j.jhydrol.2007.10.062.

Jodeau, M., A. Hauet, A. Paquier, J. Le Coz, and G. Dramais. “Application and Evaluation of LS-PIV Technique for the Monitoring of River Surface Velocities in High Flow Conditions.” Flow Measurement and Instrumentation 19, no. 2 (2008): 117–27. https://doi.org/10.1016/j.flowmeasinst.2007.11.004.

Jodeau, Magali, Alexander Hauet, Jerome Le Coz, Yvan Bercovitz, and Franck Lebert. “Laboratory and Field Lspiv Measurements of Flow Velocities Using Fudaa-LSPIV a Free User-Friendly Software.” Madrid, 2017.

Leitão, João P., Salvador Peña-Haro, Beat Lüthi, Andreas Scheidegger, and Matthew Moy de Vitry. “Urban Overland Runoff Velocity Measurement with Consumer-Grade Surveillance Cameras and Surface Structure Image Velocimetry.” Journal of Hydrology 565 (2018): 791–804. https://doi.org/10.1016/j.jhydrol.2018.09.001.

Muste, M., H. -C. Ho, and D. Kim. “Considerations on Direct Stream Flow Measurements Using Video Imagery: Outlook and Research Needs.” Journal of Hydro-Environment Research 5, no. 4 (2011): 289–300. https://doi.org/10.1016/j.jher.2010.11.002.

Patalano, Antoine, Carlos Marcelo García, and Andrés Rodríguez. “Rectification of Image Velocity Results (RIVeR): A Simple and User-Friendly Toolbox for Large Scale Water Surface Particle Image Velocimetry (PIV) and Particle Tracking Velocimetry (PTV).” Computers & Geosciences 109 (2017): 323–30. https://doi.org/10.1016/j.cageo.2017.07.009.

Tauro, Flavia, Fabio Tosi, Stefano Mattoccia, Elena Toth, Rodolfo Piscopia, and Salvatore Grimaldi. “Optical Tracking Velocimetry (OTV): Leveraging Optical Flow and Trajectory-Based Filtering for Surface Streamflow Observations.” Remote Sensing 10, no. 12 (2018): 2010. https://doi.org/10.3390/rs10122010.

Turnipseed, D. Phil, and Vernon B. Sauer. “Discharge Measurements at Gaging Stations.” Reston, Virginia: U.S. Geological Survey, Techniques and Methods book 3, chap. A8, 87 p., 2010.