An Innovative Camera-based Flow Monitoring and Flood Early Warning System

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Abstract

Particularly during extreme events, precise knowledge of the discharges in flowing waters is of great and decisive interest. Conventional measurement methods, however, reach their limits precisely then, as they often rely on a sensor that is not contactless. Image-based flow measurement systems offer a flexible non-intrusive alternative with real time measurement. Unlike conventional measurement methods, the ratio of measurement signal to measurement noise is optimal for extreme events. In the present paper, two extreme flood events are presented, which occurred under completely different conditions. A camera-based discharge system (DischargeKeeper) is permanently installed in northern Spain on the northern slopes of the Pyrenees. In November 2021, an event with a 500-year return period was recorded there. Most of the conventional measuring systems installed at this station were destroyed during the flood event but the camera-based system remained intact because it could be mounted on the side of the cross-section far enough away from the flood water. The measured discharge at the flood peak was 980 m^3/s.
The second case study is about an event in a wadi in the United Arab Emirates (UAE). Wadis are completely dry during most of the time. However, flash floods must then be expected during the very rare but equally heavy rainfall. In April 2021, a DischargeKeeper system was installed in Wadi Naqab in the northern UAE. The wadi is about 100m wide and was completely dry for two years. In January 2022, a first such event was recorded. Within 15 minutes, the flow increased from 0 m^3/s to 78 m^3/s.
The specific requirements and challenges in such extreme flood situations are presented in this paper.

1. Introduction

Real-time flood monitoring is becoming more and more important in recent years. Reliable river water level and discharge data are crucial for flood monitoring and for the design of flood protection measures. However, discharge measurements during flood events are difficult to obtain resulting in a lack of data during those events. Many discharge measuring systems with different measuring principles can be implemented for this purpose. However conventional discharge systems must be installed within the stream cross-section or on a bridge above the water surface. Therefore, these systems are mostly impaired or fail completely during flood events.

In the last years several image-based methods were developed and have been successfully applied to a variety of situations. (Fujita et al., 1998; Hauet et al., 2008; Muste et al., 2008; Dramais et al., 2011). In recent years, camera-based technologies for water level, velocity and discharge measurements have become very robust (Peña-Haro et al., 2021). Image velocimetry showed clear advantages against conventional systems for flow measurement under high flow conditions (Jodeau et al., 2008; Le Coz et al., 2010; Fujita and Kunita, 2011), especially because they are not in contact with water. Even more, these technologies have been used to analyse video from social media (Le Boursicaud et al., 2016) and surface velocity and stream discharge had been measured from video footage acquired with unmanned aerial vehicles (Detert and Weitbrecht, 2015; Tauro et al., 2016).
Herein, the application of image-based methods during flood events are presented here are based on two case studies. In both cases a stationary camera-based discharge system (DischargeKeeper) is installed. The first site is in northern Spain where a 500-year flood event was measured. During that event other installed devices, which were in contact with the water, were flooded away. Since the camera was far enough from the water it was not damaged, and it measured the whole extreme flood event. In the second case study, the system was installed in very different environment, in a Wadi in the United Arab Emirates. Wadis are dry almost all year round, but they are prone to flash flood events. In the one recorded, the peak of the event arrived just 15 minutes after the water started flowing and lasted for some hours before coming dry again.

2. Methods

Camera-based technologies apply the velocity-area method for discharge calculation: $Q=A\cdot v_b$, where A is the wetted area (m^2) and v_b is the bulk velocity (m/s). The current cross-section and the water level are required to calculate the flow area. The bulk velocity is calculated based on the measured surface velocity measured by image analysis. To obtain the surface velocity using images, different methods are available such as Large-Scale Particle Tracking Velocimetry (LSPTV), Kanade-Lucas Tomasi Image Velocimetry (KLTIV), Optical Tracking Velocimetry (OTV), Surface Structure Image Velocimetry (SSIV), or Space Time Image Velocimetry (STIV). In this work, it was used the camera-based measuring system DischargeKeeper (DK) developed by SEBA Hydrometrie GmbH & Co. KG and Photrack AG , which has implemented the SSIV (Lüthi et al., 2018) . The measuring system consists of an IP-camera, an infrared beamer for measuring at night and a central unit with remote data transmission. The implemented algorithm is running in real-time on the device to provide on-site measurement and evaluation. The measuring process including recording image streams takes less than one minute. This enables very short measuring intervals which is very beneficial for flood monitoring.

In addition to the digitized measured values, proof images and videos are stored and can be transmitted to an FTP server. Independently of the method implemented, to obtain the discharge from videos the following main steps are required: the first step is Camera calibration, which allows to make transformation between image space and the real world, during these procedure the camera’s internal and external parameters are obtained. Camera calibration is done by positioning Ground Control Points, getting its 3D coordinates and its correspondence on the image.
The second step is image orthorectification. Once the correspondence between image space and object space has been established via camera calibration, the images are orthorectified and at the same time, they can be corrected for lens distortion. The third step is water level estimation. Water level is a key quantity when calculating the discharge, together with the cross-section, it is needed to obtain area to be used in for the discharge calculation. There are several ways to obtain the water level, from image-methods (see Peña-Haro et al., 2021) or it can be gotten from external sensors.

The fourth step is surface velocity calculation. The system presented herein have implemented the SSIV method (Lüthi et al., 2018) which is based on a cross correlation technique and has several common features with LSPIV. SSIV applies a filter to the images prior the cross correlation to reduce the influence of glare and shadows and to enhance structures that are present on the free flow surface. All analysed images are subdivided into interrogation windows on which the cross-correlation algorithm is applied, yielding a displacement field. Then, using the camera calibration, the displacement field can be transformed into velocities in metric units. The fifth step is depth average velocity and discharge calculation. Once the surface velocity is obtained, and assuming the cross section of the stream and river stage are known, it is then possible to calculate the discharge by integrating the depth-averaged velocity over the width of the river. To calculate the depth-averaged velocity several approaches are available, from physically-based models to fully empiric models. In the systems shown here, the ISO 748 (2007) was used. Image-base methods are very flexible, since the sensor is a camera which can be mounted anywhere as far as it has a view of the full width of the flow and good resolution. The camera can be mounted in almost any position relative to the flow.

3. Results and discussion

The discharge measuring system of the first case study in northern Spain was installed in February 2021. A 500-year return event was measured at the first site in Spain. The measuring system was installed at a monitoring station, together with other systems for measuring the discharge. The monitoring station is located at a control canal. The IP-camera was mounted on the wall of a house outside the canal cross-section area. In November 2021 a 500-year event took place, the high flows destroyed much of the equipment which was in contact with the river. The water even reached the house, but not the camera. Figure 1 shows three different flow conditions with discharge values from 100m^3/s to 980 m^3/s withing the year 2021. While the left image shows a sudden water level increase occurred at night, the image in the middle shows a relatively moderate flood event with about 200 m^3/s discharge. The image on the far right shows the maximum condition with about 975 m^3/s discharge close to the flood peak. It was possible to get the river stage using an existing water level sensor which is housed inside the monitoring station and was not affected by the flood.

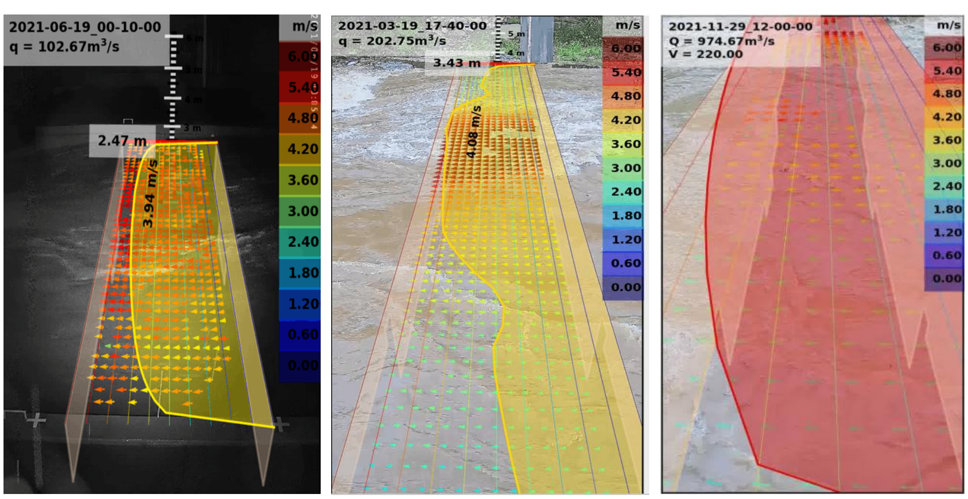

Figure 1. proof images at different flow and lighting conditions on a DischargeKeeper site in Spain

The hydrograph of the event is shown in Figure 3, the maximum measured discharge was 980 m^3/s.

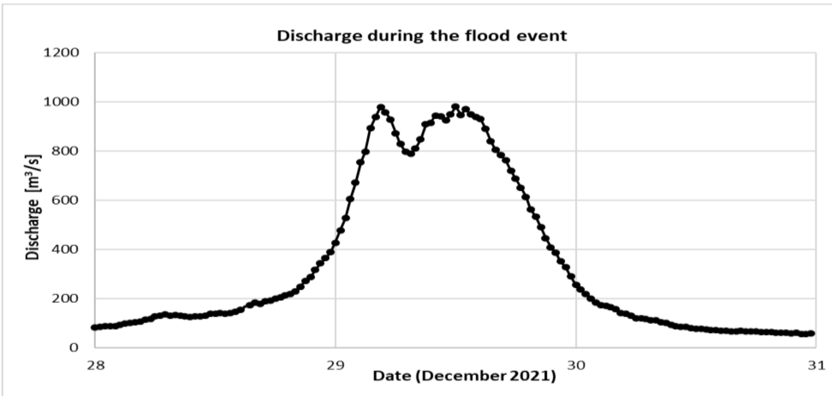

Figure 2. hydrograph of the flood event measured by the DischargeKeeper site in Spain

The second case study is about a flash flood event in a wadi in the United Arab Emirates (UAE). Wadis are completely dry during most of the time. However, flash floods must then be expected during the very rare but equally heavy rainfall. In April 2021, a DischargeKeeper system was installed in Wadi Naqab in the northern UAE. The wadi is about 100m wide and was completely dry for two years. The camera installed on this site is a PTZ-camera (Pan-Tilt-Zoom) with a range >200m and the measuring system is solar-powered.

In January 2022, a first flood event was recorded. Within 15 minutes, the flow increased from 0 m^3/s to 78 m^3/s (see Figure 3). Discharge measurement in semi-arid regions is a major challenge due to their harsh and continuously changing environment. Wadis are normally dry except after a rain event, often resulting in flash floods events with flood peak values occurring in the first few minutes of the event. In April 2021 a DK was installed at the Wadi Naqab located in northern United Arab Emirates. The Wadi is approximately 50m wide and has been dry for most of the time. One event occurred at the beginning of January 2022, reaching a peak discharge of 78 m^3/s with surface velocities around 3 m/s just 15 minutes after water started flowing. Figure 3 shows an image (left) one hour before the flood and one image during the flash flood event (right).

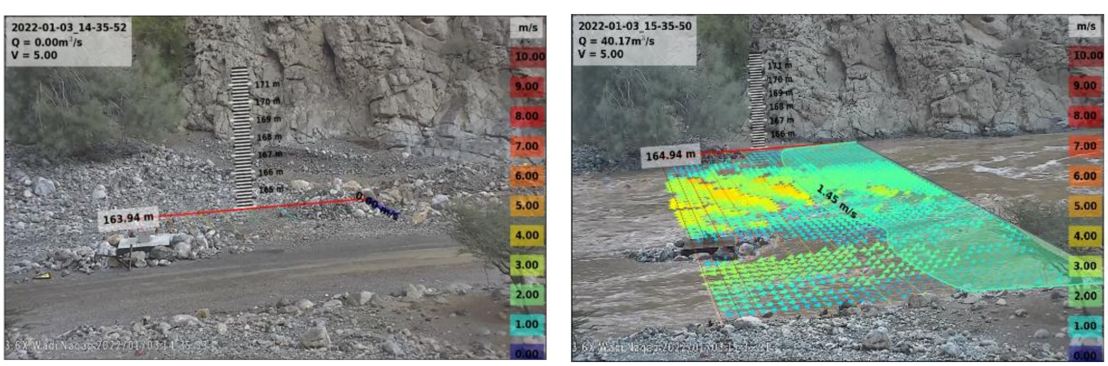

Figure 3. proof images before and during a flash flood event on a DischargeKeeper site in Wadi

Figure 4 shows the hydrograph of the discharge values measured by the camera-based system on the day of the flash flood event.

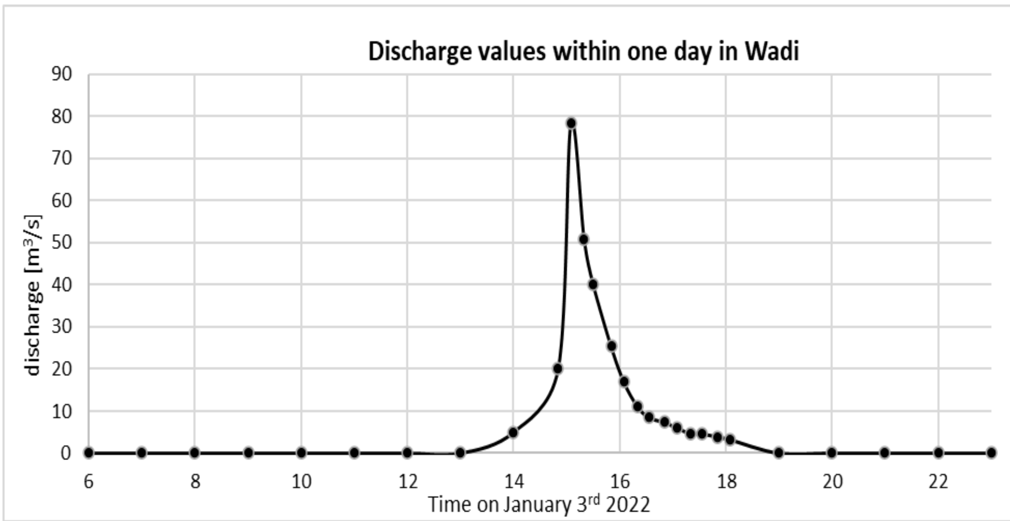

Figure 4. Discharge hydrograph of the flash flood event on a DischargeKeeper site in Wadi

4. Conclusions

The camera-based system installed on both sites of the case studies presented could continuously provide reliable measured data. The transmitted proof images were very helpful for the optical verification of the measurement especially during the flood events. Furthermore, the camera used can be installed at almost any position with respect to the flow, regardless of the presence of a bridge, as far as the flow is in the view of the camera with a good resolution.

There were no measurement limitations even during the extreme flood events on both sites. This is mainly because the sensor is a camera which can be permanently mounted at a safe distance from the flow outside the cross-section and the flood area. Due to the image processing method, the measuring system does not need to come into contact with the measured medium, which means that mud or flotsam do not affect the operation of the implemented measuring system. Only the camera lenses and the glass of the illumination unit must be free of dirt. Thus, the measuring system is almost maintenance-free and causes hardly any operating costs.

Furthermore, it is possible to install either one camera with one image view, several cameras with one image view each or one PTZ camera with several image views. Therefore, the DischargeKeeper can be used for rivers or canals with a width of a few metres up to several hundred metres. The infrared illumination of the measuring system enables operation in the most varied weather and light conditions.

A special feature of the technology is that no detectable tracers or floating objects need to be present to measure the flow velocity. Sufficient roughness on the water surface and profile data are the only requirements of the measuring system.

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