An Innovative Image Processing Method for Flow Measurement in Open Channels and Rivers

I.Hansen[1], R. Warriar[1], C. Satzger[1], M. Sattler[1], B. Luethi[2], S. Peña-Haro[2], R. Duester[1]

[1]SEBA Hydrometrie GmbH & Co. KG, Gewerbestr. 61A, 87600 Kaufbeuren, Germany
[2]Photrack AG, Ankerstr. 16a, 8004 Zurich, Switzerland
Contact: Dr. Issa Hansen
e-mail: hansen@seba.de
Phone: +49 (0) 834196480
Fax: +49 (0) 8341964848

ABSTRACT

The discharge parameter, also known as the volumetric flow rate of a fluid, is defined as the water volume passing over the cross-section per unit time. The discharge is one of the most important but also the most demanding parameters within the fields of hydrology and hydraulics. There are many different systems available for measuring these variables, however most of them are intrusive (i.e. must be located within the stream). There are some other systems that are non-intrusive, but they are constrained in their relative orientation with respect to the water surface (e.g. radar systems). Image processing methods are a revolutionary measuring technique and possess certain clear advantages since there is no need for expensive installations. Furthermore, they offer more flexibility than other non-intrusive measurements systems.

SEBA Hydrometrie GmbH & Co. KG and Photrack AG have developed a new camera-based gauge for both water level and flow velocity detection, which is called "DischargeKeeper".

The DischargeKeeper is a completely new method for the continuous acquisition and storage of flow velocity profile, water level and flow rate of natural water streams, irrigation and waste water channels. The DischargeKeeper consists of an IP-camera, an infrared beamer, and a processing unit with remote data transmission. The surface velocity profile is measured by means of an optical method for capturing the flow velocity. The water level detection is carried out simultaneously by an image processing technique. Subsequently, the discharge is calculated directly on site. The equipment was tested at several sites and under different weather and light conditions. The validation of the DischargeKeeper was carried out by comparing the flow determined by the newly developed gauge, against the flow measured by a reference gauge. The correlation between the measurements carried out by the camera-based system and by the reference gauge was highly satisfactory.

Keywords: image processing, flow measurement, water level, non-intrusive measurement, velocity measurement

INTRODUCTION

The quantitative monitoring of water resources and hydraulic constructions includes the detection of basic hydraulic parameters, among other things. These are: the wet cross-section, the flow velocity and the discharge.

The flow monitoring has an increasing importance in many areas of the world, especially for flood risk management systems under the consideration of the potential influence of climate change and the reduction of natural river meadows caused by human activities. “Floods have the greatest damage potential of all natural disasters worldwide and affect the greatest number of people” (unsidr, 2002). Therefore, an effective and timely monitoring of flow rates is a very crucial factor of quantitative hydrology and water resources management.

Monitoring of surface water can be carried out by different methods. Rating curves, radar sensors and ultrasonic techniques are some of the most applied methods providing accurate and reliable data acquisition for discharge measurement or estimation. A disadvantage of these methods is the regular inspection of the site required due to environmental changes, as most of them are intrusive systems. Optical methods for water level measurement have been investigated more widely in the recent years. A significant example of water level detecting based on image processing is the camera system of HydroPix Monitoring, which is installed in a closed sewer system having the advantage that light conditions are stable without any day and night time changes and that electrical power connection is available (Nguyen, 2009). Further optical gauge system is the GaugeCam, which is designed for open channels and tested in the laboratory and at one site and proposes the usage of infrared light for night applications (www.gaugecam.com). The GaugeKeeper, a product of SEBA Hydrometrie GmbH & Co. KG, is further example for optical water level detection (Hasan et al, 2016) and (Hies et al., 2012). Other applications for both water level and velocity detection like RiverBoard (www.tenevia.com) use server based image processing which allow to connect different camera technologies but require available and stable internet connections for real-time processing. Common optical systems for flow velocity detection require visible objects (e.g. leaves or artificial tracers) on the water surface for velocity detection.

The aim of the present work is to develop a new effective method for a continuous contactless water level, velocity and discharge measurements by means of one equipment. The developed non-intrusive equipment has to be in operation even under critical conditions like floods and hydraulic jumps, under which other localized gauging methods could be temporal out of operation or not sufficiently representative. Furthermore, the developed method should be applicable independently of the presence of visible particles on the water surface. The image processing and, as a result, the obtaining of the discharge data should occur on site.

METHODS

SEBA Hydrometrie GmbH & Co. KG and Photrack AG have developed a new camera-based gauge for the continuous acquisition and storage of flow velocity profiles, water levels and flow rates in rivers, water channels and waste water channels. The completely new method is called “DischargeKeeper”, which consists of an IP-camera, an infrared beamer, and a measuring transducer with remote data transmission (see figure 1). The detection algorithm is running in real-time on the device to provide on-site measurement and evaluation. The measuring process including recording image streams takes about forty seconds. This enables very short measuring intervals (e.g. every minute). In addition to the digitized measured values, proof images are stored and can be transmitted to an FTP server via GPRS.

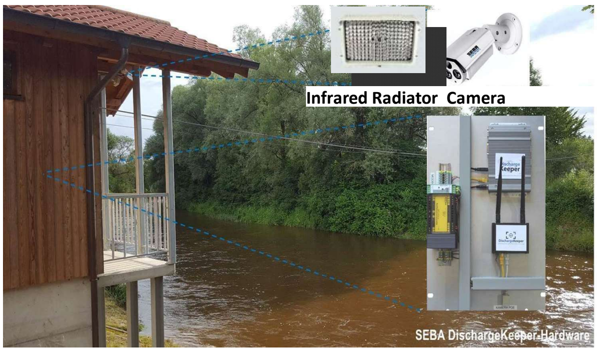

Figure 1: Hardware components of the DischargeKeeper for a typical measuring site

The calibration of the DischargeKeeper requires some input parameters. These are: the cross-section of the river/channel, the positions of at least four reference points on the far shore of the river/channel and the current position of the water line, which is equivalent to the initial water level (see figure 2). This position of the water line and the reference points are only needed when setting up a site.

The reference points can be placed anywhere, as long as they are in the camera field of vision. The x, y, z coodinates of such reference points have to be given to the DischargeKeeper.

The hydraulic input parameters (velocity and water level) can be optically detected. Subsequently, the discharge is calculated directly on site ($Q = v \cdot A\, m^3 \cdot s^{-1}$).

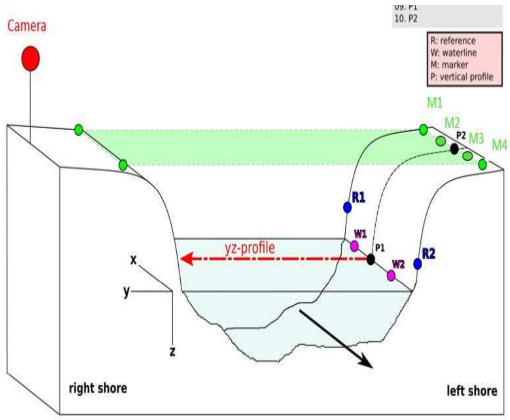

Figure 2: Schematic overview of the geometrical input parameters required for the calibration of the DischargeKeeper

The surface velocity profile is measured by means of an optical method (based on the cross correlation technique) for capturing the flow velocity. The applied optical method for velocity measurements is based on the well-established Particle Image Velocimetry (PIV) technique (Adrian, 1991), which is also known of being successfully applied to large scale free surface flows of flumes or open channels, also known as Large Scale PIV (LSPIV).

The water level detection is carried out simultaneously by an image processing technique. For the estimation of the water level several optical methods are available.

A new approach (patent pending) for water level detection was developed to separate the moving water from the rest of the image using a sequence of images. The vertical velocity profile is obtained employing a roughness dependent mixing length model (Absi, 2006) (see figure 3).

The validation of the DischargeKeeper was carried out by comparing the flow determined by the newly developed gauge, against the flow measured by a moving boat ADCP-System (Acoustic Doppler Current Profiler) as well as the discharge values, which are derived from a rating curve.

The developed method is also applicable using a mobile device App for Small Open-Channel Flow Measurement (Lüthi et al., 2014 and Peña-Haro et al., 2015).

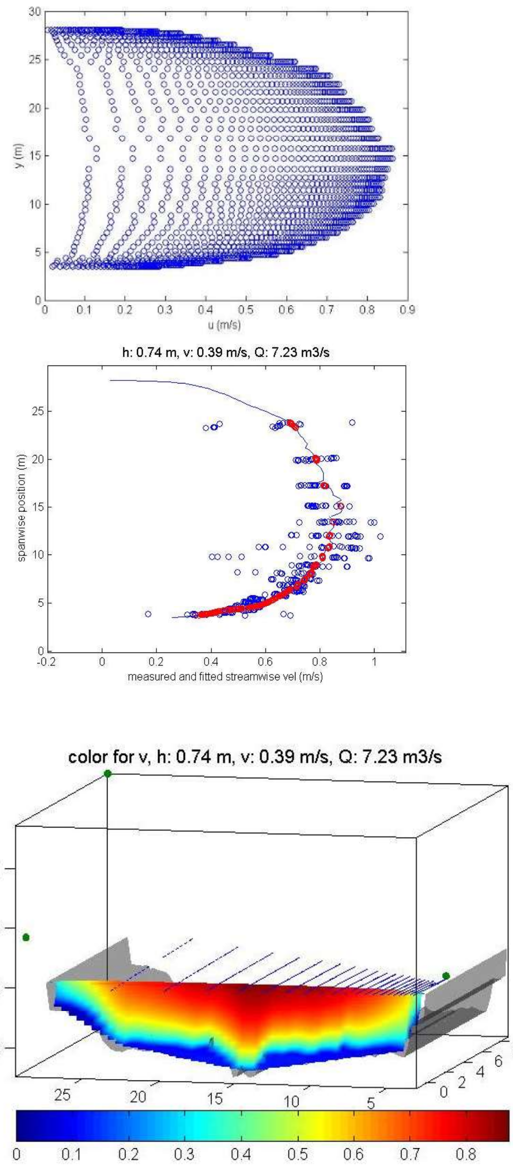

Figure 3: Overview of some measuring steps: optical detection of the surface velocity, mean velocity and model-based vertical velocity profile calculation

RESULTS AND DISCUSSION

The developed optical gauge was tested at several sites in Europe in the hydrology and waste water sectors. The main validation process of the developed system was done based on the example of the site Thalhofen, which is located in Bavaria/Germany on the Wertach River (see figure 4). The green arrows on the image are the optically detected velocity vectors on the water surface and the red line is corresponding with the optically detected water level.

Figure 4: DischargeKeeper's site on the Wertach River

The correlation between the measurements carried out by the camera-based system and by the reference gauge was highly satisfactory. The deviation between the DischargeKeeper and the ADCP measurements was less than 5% at 40% of the carried out measurements (in total 11 comparative measurements). A deviation of less than 10% and less than 15% was achieved at 60% and 80% of the carried out measurements, respectively. The difference was mostly between 0.01 m^3/s and 0.1 m^3/s (see figure 5).

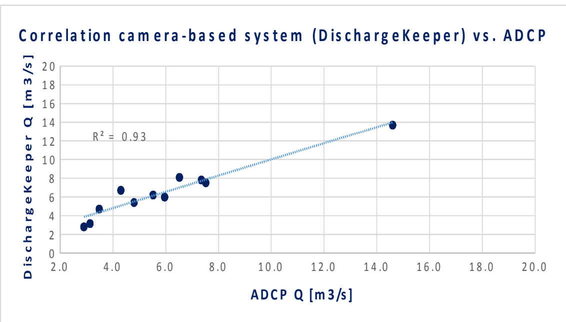

Figure 5: Correlation between the camera-based system (DischargeKeeper) the ADCP comparative measurements

In addition, the DischargeKeepers' measurements were compared with rating curve values (see figures 6 and 7). The discharge values derived from the rating curve are estimated according to the water level measurements by a floater. Therefore, some deviations were expected.

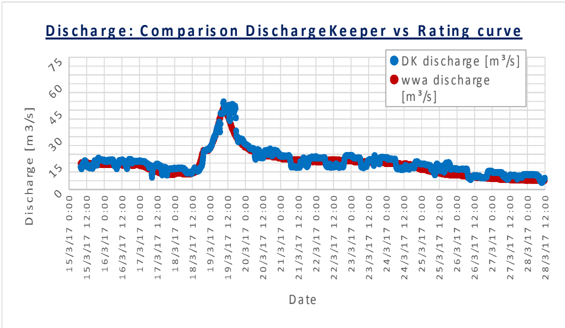

Figure 6: Comparison between the discharge values of the DischargeKeeper and the rating curve

The comparison between the rating curve and the DischargeKeeper discharge data is made to roughly check the plausibility of the data collected by DischargeKeeper. The behaviour of both curves was almost similar.

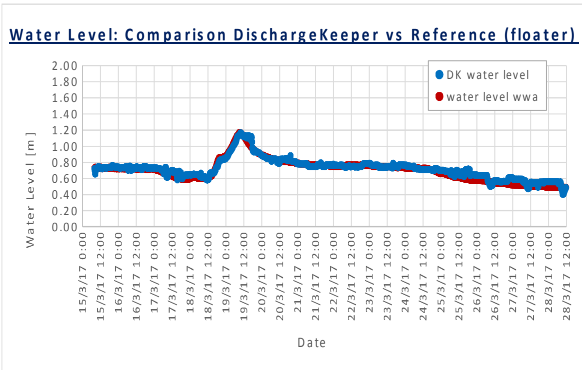

Figure 7: Comparison between the water level values of the DischargeKeeper and the floater sensor

The developed instrument is very suitable for the application in the waste water sector. The measurement by means of the DischargeKeeper is often less demanding in the waste water sector, as the cross-section there is usually more stable and the water movement is highly visible (see figures 8 and 9).

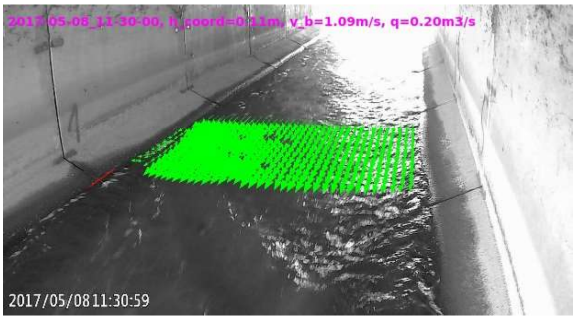

Figure 8: DischargeKeeper's measuring site on the outflow of a waste water plant

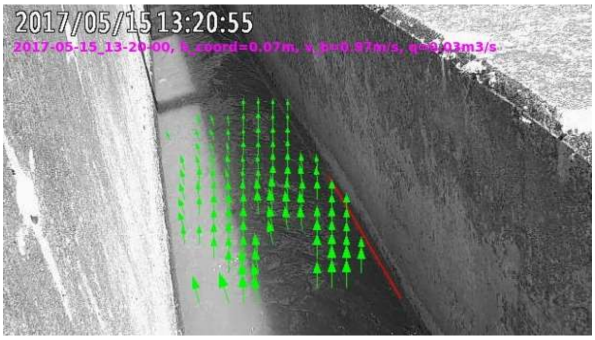

Figure 9: DischargeKeeper's measuring site on the inflow of a waste water plant

CONCLUSIONS AND OUTLOOK

The presented optical gauge was successfully verified and validated on several sites. The correlation between the measurements carried out by the camera-based system and by the reference gauge was highly satisfactory. The new developed gauge has proven to be a reliable method for flow velocity profiles, water levels and flow rates measurements and for providing a photographic evidence of every measured value. This technology is applicable for on-site measurements of the discharge in the hydrology and waste water sectors, among other things.

Due to the optical image processing method, the developed gauge system requires no contact with the measured medium. Therefore, silting or flotsam have no influence on the operation of the DischargeKeeper and it can work even in extreme events such as floods and hydraulic jumps. The distance can be up to 50 m between the camera and the far shore of the river or channel. This distance is for the default hard- and software specifications. Measuring at wider river or channels is possible after some respective adjustment and modification of the equipment's configuration.

The special lighting of the presented gauge system enables its operation under many different weather and light conditions.

A special feature of this technology is that no flow tracers need to be added for flow velocity detection. The DischargeKeeper operates on visible moving surface structures. Nevertheless, naturally occurring floating objects on the water surface (e.g. leaves) enhance the measurement signal.

Sufficient roughness on the water surface and a visible river/channel shore structures are beneficial conditions for precise measurements. Sites with high wind influence have to be avoided.

The DischargeKeeper is maintenance-free. The camera lenses and the glass of the illumination unit must be clean and free of dirt.

The developed optical gauge will be tested in the future under further weather and light conditions. A self-updating rating curve is being developed for a gapless measurement even under critical light or flow conditions.

REFERENCES

[1] Absi R. (2006). A roughness and time dependent mixing length equation. Journal of Hydraulic, Coastal and Environmental Engineering, (Doboku Gakkai Ronbunshuu B), Japan Society of Civil Engineers, 62(4), 437-446.

[2] Adrian R.J. (1991). Particle-imaging techniques for experimental fluid mechanics. Annual Review of Fluid Mechanics 23, 261-304.

[3] Hasan, I., M. Satzger, M. Sattler, R. Duester, T. Hies, E. Jose (2016). An Effective Camera Based Water level recording Technology for Flood Monitoring http://interpraevent2016.ch/assets/editor/files/IP16_CP_digital.pdf . ISBN 978-3-901164-24-8, Lucerne, Switzerland.

[4] Hies, T. Parasuraman, S.B., Wang, Y., Duester, R., Eikaas, H.S, Tan, K.M. (2012): Enhanced Wa-ter-level Detection by Image Processing. Proceedings 10th International Conference on Hydroin-formatics, HIC 2012, Hamburg, Germany

[5] Lüthi, B., T. Philippe, and S. Peña-Haro. “Mobile Device App for Small Open-Channel Flow Measurement.” In Proceedings of the 7th International Congress on Environmental Modelling and Software, June 15-19, edited by D.P. Ames, N.W.T. Quinn, and A.E. Rizzoli. San Diego, California, USA., 2014.

[6] Nguyen, L. S., Schaeli, B., Sage, D., Kayal, S., Jeanbourquin, D., Barry, D. a, & Rossi, L. (2009). Vision-based system for the control and measurement of wastewater flow rate in sewer systems. Water science and technology, 60(9), 2281-9.

[7] Peña-Haro, Salvador, Beat Lüthi, and Thomas Philippe. “Smartphone for Measuring River Discharge.,” Vol. Vol. 17, EGU2015-1847, 2015. Vienna, Austria, 2015.

[8] The United Nations office for disaster risk reduction (2002). http://www.unisdr.org/files/558_7639.pdf

[9] http://www.gaugecam.com

[10] http://www.tenevia.com

[11] http://www.photrack.ch