Development of an Inexpensive Automated Streamflow Monitoring System

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Informative/Abstract:

Estimating streamflow is time and labour intensive due to the necessity of developing a rating curve. The development of a rating curve involves acquiring at least thirty in-field measurements of streamflow across a wide range of flow levels, which can be costly and impractical in remote regions with limited seasonal access. Here we showcase an automated system which accurately estimates streamflow multiple times each day, greatly facilitating the development of rating curves for remote or seasonally inaccessible sites. The system uses an emerging technique referred to as particle image velocimetry (PIV) to track the movement of objects and flow structure features on the mobile water surface to generate velocity vector grids. Velocity grids were used to calculate streamflow and facilitate the development of a rating curve. This represents the first use of an automated PIV system to estimate streamflow in small streams (< 5 m wide) and the first system to automatically distribute particles for facilitated PIV analysis.

Keywords: Particle Image Velocimetry, Streamflow Monitoring, Automated Systems, Particle Tracer

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Project Description:

Estimating streamflow generally requires the development of a rating curve, which allows high frequency stream stage measurements to be transformed into a 'continuous' discharge series of values. The development of a rating curve involves acquiring at least thirty in-field measurements across a wide range of flow levels, which can be costly and impractical in remote regions with limited seasonal access. Here we showcase an automated system for collecting rating curve data which allows the estimation of streamflow multiple times each day, greatly facilitating the development of rating curves for remote sites.

The system uses an in-field camera to take videos of the stream surface, and then uses particle image velocimetry (PIV) techniques to estimate surface velocity. This technique was first developed in the 1980s (Adrian 1984; Pickering and Halliwell 1984; Grant 1997) and has attracted attention in recent years for its great practicality (Bradley et al. 2002; Creutin et al. 2003; Tauro et al. 2016). Videos used for PIV analysis are typically captured manually; however automated camera systems have been attempted by for large rivers > 100 m wide (e.g. Bechle et al., (2012). Hydrological imaging has been attempted on smaller, more turbulent streams (Leduc et al. 2018) primarily to assess stream height and width. No documented cases were found of stream velocity estimation from video analysis on small streams (i.e. < 5 m wide) where bank roughness takes up a large percentage of cross stream the flow field. Here we deploy an inexpensive automated camera systems on two small streams, Charles Creek and White Partridge Creek in south-central

Ontario, Canada, to test the feasibility of PIV for discharge estimation.

The automated camera system followed a process of measuring stream stage, assessing if data were required for that stage to selectively trigger the distribution of particles and video capture. Stream stage was measured every hour during periods of maximum sunlight – 10:00 until 15:00 – and a video was recorded if stage was observed to change by more than 5 cm. Polarising filters were used to limit glare as recommended by previous stream video velocimetry studies (Bradley et al. 2002; Bechle et al. 2012; Tauro et al. 2017). PIVlab was used in conjunction with the Rectification of Image Velocity Results (RIVeR) software to calculate velocity vectors from stream videos (Patalano et al. 2017). PIVlab analyzed videos frame by frame to vectorize the change in position of objects and flow structure features on the mobile water surface to generate vector grids. RIVeR then corrects the geometry of these vectors with respect to specified ground control points and uses the time between frames to calculate surface velocity vectors within the control point footprint. Streamflow was then estimated using a surface velocity to average velocity transformation and cross section area, calculated using stage and stream bathymetry data. PIV velocity and discharge estimates were calibrated and validated with field based measurements taken using a FlowTracker (SonTek 2009).

PIV streamflow estimates at the Charles Creek site were similar to in-field measurements taken with a FlowTracker. These field measurements doubled the range of flows on the rating curve relative to the in-field measurements, which are difficult to acquire during peak flows due to access issues and safety concerns, and allowed for the development of a rating curve encompassing the entire range of flows in 2018. Streamflow estimates were generally underestimated, which is common with PIV analysis (Tauro et al. 2017), however this was overcome by calibrating the adjustment factor (α) which relates surface to average velocity. After calibrating the adjustment factor, PIV estimates were similar to FlowTracker measurements for both sites. Particle distribution was not necessary at the Charles Creek site as ideal lighting and stream morphology created visible stream texture, making the site perfect for tracking water movement.

Conversely, the White Partridge Creek site required that particles be distributed into the stream, as stream surface texture was limited by the lack of visible water surface texture related to the lack of water surface roughness and turbulent boils. Further, the polarizing filter removed any differential sunlight reflection caused by the little surface roughness that was present within the reach. Thus, during low flow periods, particles were distributed into the stream via an automated feeding system to increase movement detection. Popular tracer particles are typically expensive and synthetic (Melling 1997; Grant 1997), which was unsuitable for this project. Tauro (2016) developed inexpensive biodegradable particles made from beeswax, but the scent from these particles had the potential to attract wildlife to the site. Fine woody particles were chosen as the seeding material, as they were buoyant, bio-degradable, and did not have a scent which would attract wildlife. While we recorded and processed 1.25 minutes of video for non seeded cases, some experimentation with video length required for optimal PIV processing revealed that thirty second videos provided the most accurate streamflow estimates when seeding is used in this narrow stream case, because particles near the stream banks slowed to a stop when rafting of particles occurred as the near bank region became progressively saturated with particles. Further, gaps in particle coverage opened in the center of the channel after 30 seconds and the swirly seed free areas increased in size over time. Thus, surface velocity estimates were less accurate and generally lower when averaged over longer videos. Seeking an automated camera site with surface textures over a full range of flows is the best strategy to avoid having to deal with seeding issues.

The camera system detailed here allows for inexpensive stream gauging, which can be valuable for measuring streamflow in small rivers in remote areas. The system had a battery life of approximately one month, capturing an average of two videos each day, and this could likely be extended by using a higher power efficiency Raspberry Pi model (e.g. Zero), incorporating a more sophisticated sleep cycle, reducing the frequency of videos captured, and increasing solar power.

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