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Short communication

Ice dices for monitoring stream surface velocity

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ABSTRACT

Non-intrusive observations are fundamental to monitor river flows and understand water processes in natural systems. Recently, the introduction of optical methods has fostered the establishment of numerous image-based techniques for characterizing the kinematics of water bodies. However, RGB image-based methods are still severely affected by illumination conditions and tracers' visibility. In this note, the integration of particle-shaped tracers and thermal imagery is applied to characterize the surface velocity field of a natural stream. Specifically, the trajectories of a few grams of artificially deployed ice dices are reconstructed by analyzing thermal images with particle tracking velocimetry. Average surface flow velocities are in agreement with benchmark values estimated with a current meter. This proof of concept experiment demonstrates the efficacy of thermal imagery for hydrological monitoring and paves the way to the integration of thermal signals in standard water gauging systems.

1. Introduction

Flow measurements are of paramount importance in hydrology for the establishment of discharge rating curves (McMillan et al., 2010), for flood risk forecasting (Kreibich et al., 2009), to quantify erosion dynamics (Zeng et al., 2008), and to investigate the organization of drainage networks in natural catchments (Hrachowitz et al., 2013). Flow observations are typically executed with current meters or acoustic devices at selected monitoring sections (Tazioli, 2011; Yorke and Oberg, 2002). Alternatively, non-intrusive instruments, such as radars and microwave sensors, are applied to estimate surface velocity (Costa et al., 2000; Costa et al., 2006; Fulton and Ostrowski, 2008; Melcher et al., 2002; Plant et al., 2005). Such methods enable flow measurements over areas of limited extent, and their implementation can be costly.

In latest years, optical methods have proved beneficial for non-intrusive environmental monitoring. Images provide spatially distributed observations of flow kinematics and can be captured from remote locations, thus enabling flow monitoring in adverse hydro-meteorological conditions and difficult-to-access stream sections (Tauro et al., 2014). Several image-based algorithms have been conceived to reconstruct the surface flow velocity field from images (Fujita et al., 1997; Fujita et al., 2007; Quénot et al., 1998). For instance, large scale particle image velocimetry (LSPIV) has been applied in diverse environmental conditions from fixed (Hauet et al., 2008; Jodeau et al., 2008) and aerial platforms (Fujita and Hino, 2003; Fujita and Kunita, 2011; Tauro et al., 2015). This approach is potentially applicable to continuously monitor water bodies, and its implementation can be fully non-invasive by adopting remote laser-based image calibration systems (Tauro et al., 2014). However, optical methods are highly affected by image quality. For instance, severe illumination conditions, such as direct sunlight or rather dark shadows, and the presence and spatial distribution of floaters control LSPIV accuracy (Tauro et al., 2016), thus considerably limiting its systematic use in engineering practice.

Similar to regular cameras, thermal cameras allow the observation of rather extended areas without the deployment of sensors in the water current. Also, thermal signal is less affected by water surface reflections and illumination conditions than RGB imagery, and it can be sensed both in daylight and nighttime conditions. In hydrology, thermal signals are typically used for investigating thermal processes and patterns in water systems (Aubry-Wake et al., 2015; Torgersen et al., 2001). Optical-based algorithms, such as particle image velocimetry (PIV) (Adrian, 2005; Raffel et al., 2007), have been applied to thermal images in laboratory and environmental applications (Jackson et al., 2009). For instance, such an approach has been used to study two-dimensional wind velocity

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field (Inagaki et al., 2013) and flow turbulence (Chickadel et al., 2011). Image-based algorithms have also been used to track surface objects in oceans from unmanned aerial vehicles (Leira et al., 2015). In (Puleo et al., 2012), river surface currents are reconstructed using time sequences of water surface emissivity observed with an infrared camera. In addition, the combined use of thermal imagery and thermal tracers (in most instances hot liquids) has been instrumental to study microrelief structures in hills (deLima and Abrantes, 2014) and to estimate surface velocity in rills (deLima and Abrantes, 2014). In (deLima and Abrantes, 2014), the optimal visibility of thermal tracers is exploited to estimate travel time along selected paths, and, therefore, to infer average flow velocity.

Leveraging enhanced optical properties of thermal images, in this note, we propose a novel application of thermal signals that integrates particle-shaped thermal tracers and thermal cameras for distributed sensing of environmental flows. Specifically, in this work, we characterize the kinematics of a stream surface by capturing image sequences with a portable thermal camera apparatus. Similar to (Tauro et al., 2014), in this simple setup, the axis of the camera is maintained perpendicular with respect to the water surface, thus circumventing the need for image orthorectification through ground reference points. Ice dices are utilized as thermal tracers, whereby small amounts of material are deployed onto the stream water surface during image acquisition. Particle tracers' trajectories are reconstructed off-line by analyzing thermal images with a particle tracking velocimetry (PTV) algorithm. Given the optimal visibility of the tracers and their low seeding density, PTV allows for efficiently following tracers' paths in reasonable computational times. Measurements performed with a current meter provide benchmark velocity values.

Different from previous applications, here, we propose a highly-visible and inexpensive particle tracer for remote surface flow velocity measurements. Further, the proposed approach is relatively unaffected by illumination and flow seeding conditions, and it is inherently suited to be implemented in existing gauging stations for autonomously monitoring surface flows. The optimal environmental compatibility of ice dices and their relative ease of preparation and storage suggest that the technique could be easily implemented to rapidly and non-invasively characterize surface flows.

The rest of the note is organized as follows. In Section 2, details are provided on the study site, experimental equipment and tests, and image-based processing techniques. In Section 3, results are illustrated and commented; and concluding remarks are reported in Section 4.

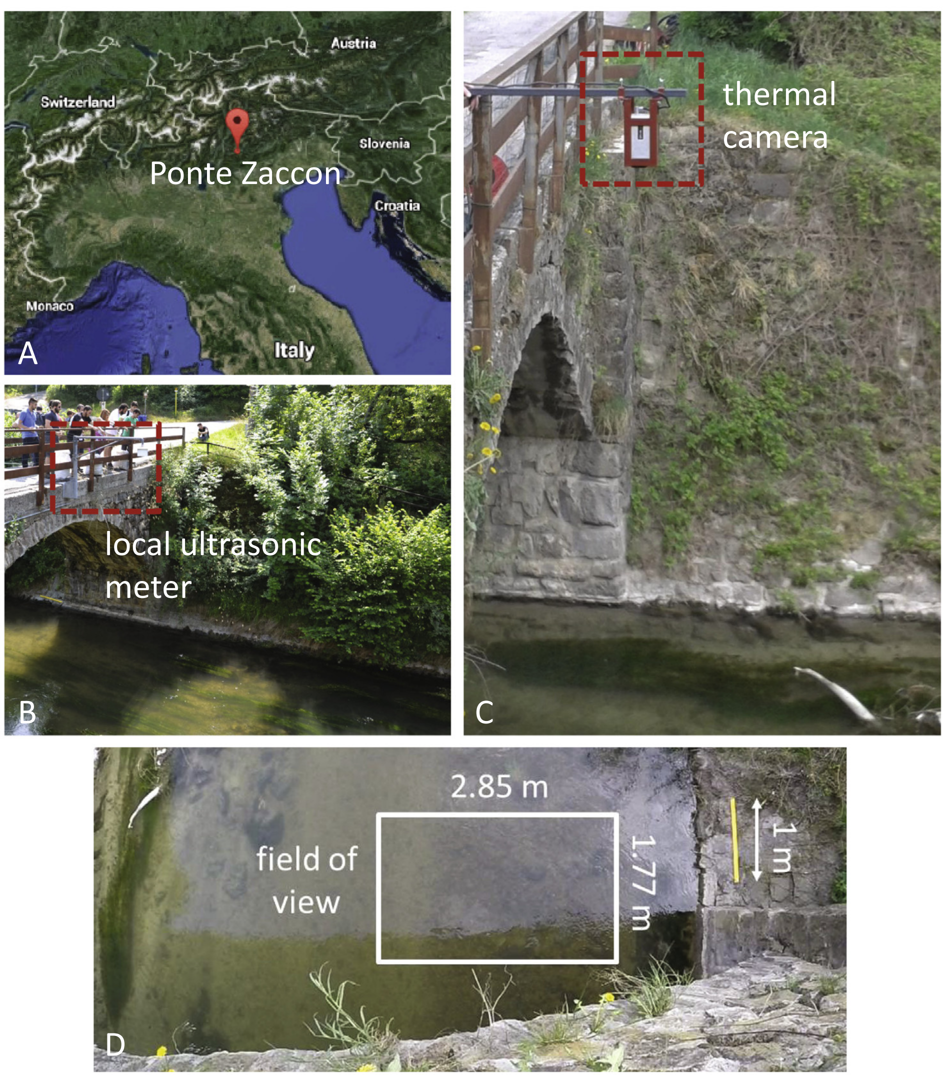

Fig. 1. Experimental site: (a) Ponte Zaccon, Trento; (b) local monitoring station; (c) thermal camera setup; and (d) region of the stream surface captured by the camera.