The potential of an enhanced LSPIV method to estimate urban overland flow velocity

Le potentiel d'une méthode LSPIV améliorée pour estimer la vitesse d'écoulement de ruissellements en milieu urbain

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RÉSUMÉ

Les modèles numériques sont des outils importants pour évaluer les risques d'inondation. Ces modèles sont des représentations abstraits de la réalité contenant de nombreux paramètres qui doivent être ajustés pour reproduire les phénomènes désirés. Bien que les modèles d'inondation ont pour but principal de simuler le ruissellement et l’accumulation d’eau, en pratique ils sont calibrés à l'aide de mesures d'écoulement à l'intérieur du système de drainage souterrain et, dans de nombreux cas, pendant les périodes sèches ou pendant de petites précipitations. Dans le cadre de la présente étude, nous avons testé l'application d'une méthode *Large Scale Image Velocimetry* (LSPIV) améliorée, avec des images vidéo obtenues à partir de caméras de surveillance, pour mesurer la vitesse d'écoulement par voie terrestre. Les résultats ont été comparés aux mesures de référence de la vitesse d'écoulement d'un capteur radar. Les résidus moyens des sept expériences sur les inondations réalisées dans des conditions d'éclairage différentes étaient inférieurs à 20%.

ABSTRACT

Flood models are important tools to assess flood risk. Models are representations of the reality that rely on many parameters that need to be calibrated to provide accurate results. Despite the focus of flood models is on overland flow, they are calibrated with flow measurements from inside the underground drainage system and, in many cases, during small rainfall events. In this study we tested the application of an improved Large-Scale particle Image Velocimetry (LSPIV) method with video footage obtained from surveillance cameras to measure overland flow velocity. The results were compared with flow velocity measurements from a radar-based sensor. The mean residuals for the seven flood experiments with different light conditions were smaller than 20% but with some measurement gaps.

KEYWORDS

LSPIV: Large-Scale Particle Image Velocimetry, urban runoff, surveillance cameras

1 INTRODUCTION

In urban flood models, rainfall data are combined with terrain surface properties, such as elevation and imperviousness. These models are usually calibrated based on flow measurements obtained (i) during dry weather periods or small rainfall events, from (ii) flow sensors installed inside the underground system of sewer pipes. These measurements are therefore only an approximation of the hydraulic conditions observed during flood events, as the operation of the system may change when the sewer systems becomes surcharged (e.g. water leaving the system via combined sewer overflow structures or through manholes). In addition to flow measurement in sewers, overland flow measurements (e.g. water depth, flow velocity and discharge) should be included. However, conventional flow sensors (usually installed in contact with the flow) are not adequate to be installed for surface flow measurement – they require frequent maintenance and would be exposed to citizen interaction (e.g. vandalism).

We performed an evaluation of a recent Large-Scale Image Velocimetry (LSPIV)-based method, called SSIV: Surface Structure Image Velocimetry (Leitão et al., 2018), to measure overland flow velocity in a dedicated real-scale flood facility (Moy de Vitry et al., 2017). The images to perform the SSIV measurements were generated from consumer-grade surveillance cameras similar to those found nowadays in many cities for citizen security and road traffic control purposes. The results showed that the flow velocity results generated using SSIV are as accurate as those obtained from radar-based results.

2 RELATED WORK

Particle Image Velocimetry (PIV) (Adrian, 1991) is a non-intrusive method for measuring flow velocity in laboratory conditions that uses cross-correlation methods on consecutive image frames of a known time interval. Based on the PIV principle, previous studies have shown that Large-Scale PIV (LSPIV) can provide reliable surface and bulk (average) flow velocities (e.g. Benetazzo et al., 2016; Fujita and Aya, 2000); although most of its applications have focused on river hydrology. Only a few studies have been conducted to evaluate LSPIV method to estimate flow velocity on shallow water conditions (e.g. Meselhe et al., 2004; Muste et al., 2014). These studies showed also good flow velocity accuracy, but were conducted in laboratory conditions.

3 SSIV: SURFACE STRUCTURE IMAGE VELOCIMETRY

In this study, we used an advanced version of LSPIV called Surface Structure Image Velocimetry (SSIV). The main feature of SSIV is that it is optimized to derive velocity from naturally occurring reflections and patterns in the water and does not require artificial seeding of particles. With these improvements, SSIV is exceptionally robust in challenging measurement situations. SSIV has been used to estimate river discharge with mobile phone cameras (Lüthi et al., 2014). For details on the SSIV method, see Leitão et al. (2018).

4 ESTIMATION OF OVERLAND FLOW VELOCITY IN URBAN AREAS

The data set used to validate the SSIV flow velocity estimation results was generated through a series of flood experiments conducted by Moy de Vitry et al. (2017). Seven events that cover various light (direct sunlight, overcast, artificial visible light and no-visible light conditions) and flow conditions were used. The SSIV flow velocity measurements calculated based on video footage from two cameras were compared with radar-based sensor measurements (see Table 1).

Table 1. Characteristics of the radar-based flow sensor and the cameras

Sensor type	Measurement frequency (s)	Distance to the flow (m)
Radar-based sensor	5	1.0
Camera 1	5	3.2
Camera 2	5	9.7

The main research questions were:

- How accurate are SSIV results for overland flow velocity measurement in urban areas?
- What is the impact of light conditions on overland flow velocity measurement with SSIV?

In order to evaluate the accuracy of the SSIV method on estimation overland flow velocity estimation using videos acquired by consumer grade surveillance cameras, we first conduct an exploratory visual analysis, followed by statistical and regression analyses.

5 RESULTS

The overland flow velocity estimates obtained using the SSIV method do not differ significantly from the velocity measured by the radar-based flow sensor. The mean difference is below 20%. However, in some conditions, the SSIV results present measurement gaps. The mean and standard deviation for the experiment conducted in the absence of visible light (i.e. with infrared light) are acceptable and suggest that infrared light (850 nm wavelenght) conditions could be a promising means of obtaining good results at night or in enclosed environments.

6 CONCLUSIONS

We have investigated the potential of SSIV (in conjunction with state-of-the-art radar-based flow sensor) for measurement of overland flow velocity in urban areas. To our knowledge, this was the first time that LSPIV-based methods are applied to urban overland flow applications. In a direct comparison, we demonstrated that in certain conditions SSIV delivers measurements that are close to traditional, radar-based flow measurements. The results suggest that the SSIV method with off-the-shelf cameras are a viable alternative for applications in urban water management, providing flexible data acquisition at relatively low cost.

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