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EMERGING EARTH OBSERVING PLATFORMS OFFER NEW INSIGHTS INTO HYDROLOGICAL PROCESSES

BY MATTHEW F MCCABE & SALVATORE MANFREDA

Data, and its timely delivery, presents one of the major constraints in advancing the hydrological sciences. Traditional monitoring techniques are time consuming, expensive, and discontinuous in space and time. Moreover, field observations are influenced by instrumental degradation and human errors. While providing the foundation upon which much of our hydrological knowledge is based, new observational strategies are required to drive further understanding and insights. Recent advances in earth observation (EO) technologies present a new frontier for hydrologic monitoring and process description [1, 2].

If a goal of the hydrological sciences is to further advance our understanding and description of the underlying physical processes and mechanisms, traditional monitoring approaches are unlikely to provide the level of detail required to do this, for both technical and economical limitations. Indeed, our ability to monitor system processes in the face of recent climate and anthropogenic changes is being increasingly compromised by the significant decline in the number of monitoring installations over the last few decades[3]. The dynamic nature and inherent variability of many hydrological processes dictates a need for both high spatial and high temporal resolution data. New approaches and technologies that augment traditional monitoring systems are required.

Field measurements still represent the "gold-standard" in observational practice, and it is unlikely that anything will supplant the insights that a quality in situ monitoring network can provide. However, recent technological advances in both satellite and nearer-to-earth platforms[2] have redefined our capacity to observe and monitor processes through time, and over large spatial domains, in ways that are not possible via ground-based measurement alone. In particular, new CubeSat satellite platforms [4], unmanned aerial systems (UAS)[1], and even high-definition video cameras [2], offer the possibility to monitor the earth system in ways that existing ground-based infrastructure cannot. These observational advances rely, in large part, on technological developments deriving predominantly from the mobile phone and related consumer electronics industry, which has driven sensor miniaturization and relatively low-cost electronics that have enhanced communication, storage and power-supplies. More specifically, the proliferation of low-cost digital cameras with high-quality sensors and large on-board storage, has enabled a new range of optically-based hydrological monitoring efforts. Indeed, several authors have exploited these technologies using novel image processing algorithms to investigate snow cover detection [5], derive rainfall intensity, [6] and measure streamflow velocity [7], to name just a few applications.

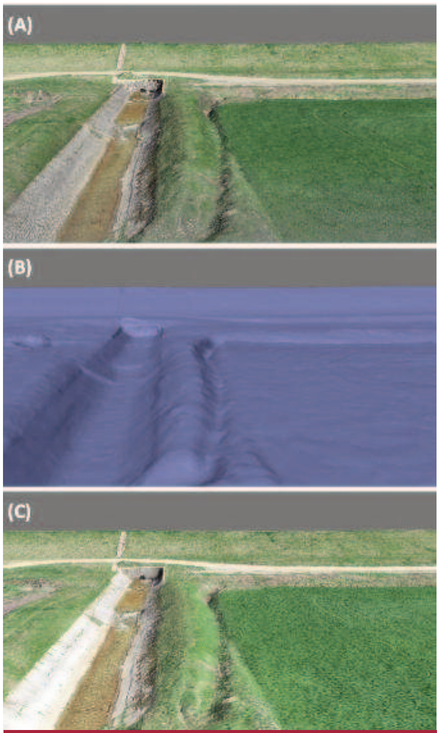

Figure 1. (A) UAS derived 3D dense point cloud, (B) mesh model, and (C) tiled model derived from a UAS based survey of an earthen dam next to the village of Pi chia (Timisoara, Romania). Such data provide the framework for development of high-resolution flood modeling, urban watershed mapping and civil engineering design and map updating [20]

While certainly not new in terms of spectral sensing capabilities, optical techniques provide an efficient and non-invasive method for a variety of hydrologic monitoring tasks. One of the most mature applications of optical sensing from UAS is the use of computer vision approaches (i.e. structure-from-motion) to reconstruct three-dimensional surfaces, allowing previously unheard of resolutions and accuracies that can inform the production of digital surface and elevation models [8]. The capacity to map both urban and natural landscapes [9] and to respond to dynamically changing surface fields, represents a critical advance in hydraulic assessment, particularly for flood mapping and response [10] (see Figure 1). More advanced applications of image and video capture from UAS include flow visualization methods that can yield a spatially distributed estimation of the surface flow velocity field, based on the similarity of image sequences. Proof-of-concept experiments have demonstrated the feasibility of applying these methods to monitor flood events from crowd-sourced imagery [11], or even to reconstruct velocity fields of natural stream reaches [12]. As an example, Figure 2 presents the use of optical velocimetry measurement over the Bradano river in Southern Italy. The optical image used for the analysis is also reported with two insets describing features of the free water surface that can be used in a flow tracking algorithm.

One of the key attributes of UAS systems that sets them apart from other earth-observing platforms is their capacity to act as an interchangeable multi-sensor platform. While simple optical sensors provide a foundation for mapping and monitoring activities, expanding

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these into the multi- and hyper-spectral domain, or exploiting LiDARbased technologies, opens up a range of insights into diverse topics including water quality [13], soil erosion and contamination [14], vegetation health and structure [15, 16], and even near-shore bathymetric measurements [17]. From a hydrologic perspective, it is this multi-sensing capability that positions UAS as a game-changing tool for driving observational analysis. Through exploiting a single platform, a unique and multi-faceted sensing framework is enabled.

The emergence of these new observational platforms present both opportunities and challenges that will need to be addressed by the broader research community, for their potential is yet to be fully realized. There are a number of international projects or initiatives that have been mobilized to support this task. Among others, two that we are involved in seek to address some of the implementation and adoption issues. The recently funded European Cooperation in Science and Technology (COST) HARMONIOUS "action" (https://www.costharmonious.eu) is one such effort to channel competencies, knowledge, and technologies around the application of UAS. In establishing an international network of more than 100 researchers from 32 countries, its purpose is to identify common strategies in environmental monitoring to exploit UAS technologies, including direct applications in the hydrological sciences. The Action is structured around five working groups (WGs) that seek to establish optimal strategies for data processing, monitoring of vegetation, soil water content, river systems and discharge, and the harmonization of these outcomes (and algorithms) across environmental gradients.

Another community effort that is folded within the International Association of Hydrological Sciences (IAHS) Panta Rhei [18] initiative, is the Measurements and Observations in the XXI century (MOXXI) Working Group (WG), which aims to focus on advancing our monitoring and data analysis capabilities to predict and manage hydrological change [19].

MOXXI promotes new monitoring approaches in order to increase the quality and resolution of hydrological observations by creating a nexus of scientists with a shared interest in sensors and novel observations spanning ground-based measurements to proximal and remote sensing. We are in a golden era of earth observation, with hydrological sciences awash with data. What is lacking are techniques to channel this information deluge into useable content and to drive knowledge advances. Guidance on how to exploit crowd-sourced data, to leverage UAS and satellite platforms, and to interrogate the massive data streams that will continue to be produced are all required. Community efforts that provide structure and strategy to this mission will be central to realizing the potential for technology driven insights in the hydrological sciences. ■

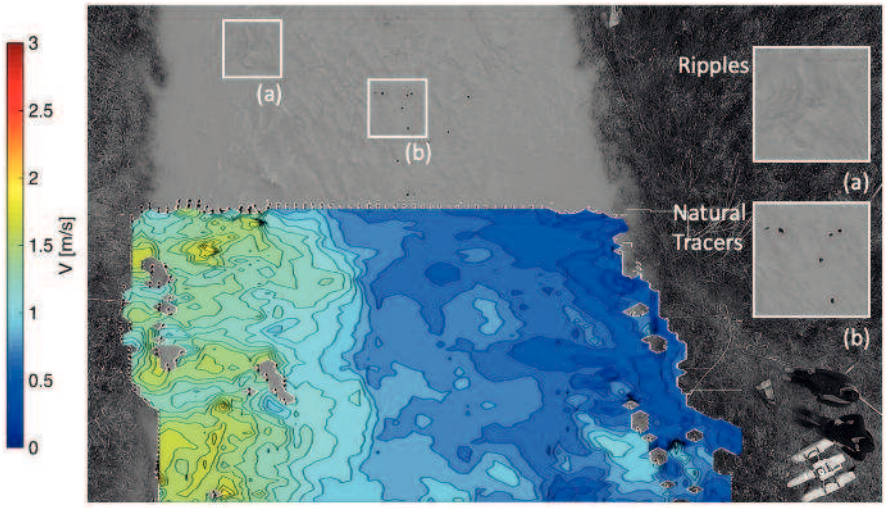

Figure 2. A 2-D flow velocity field derived using an optical camera mounted on a quadcopter hovering over a portion of the Bradano river system in southern Italy. One of the images used for the analysis is shown as a background, where surface features used by flow tracking algorithms are highlighted in the insets (a, b)

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