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RIVERS 2.0 – TRANSFORMING RIVERS INTO DIGITAL LANDSCAPES USING UNMANNED AERIAL VEHICLES

BY CHRISTIAN HAAS, PHILIPP THUMSER & JEFFREY A. TUHTAN

Rivers are best viewed from above, and unmanned aerial systems (UAS) provide an excellent means to collect digital imagery and data in challenging environments. UAS are now commonly used in archaeology, geography, mining, and civil engineering. The measurement and mapping of hydrosystems using UASs is both lean and agile, with the added advantage of increased safety for the surveying crew. Here we provide an overview of how UAS can be used to create new sources of digital information, ushering in the age of what we refer to as Rivers, 2.0.

State of the Art in UAS applications

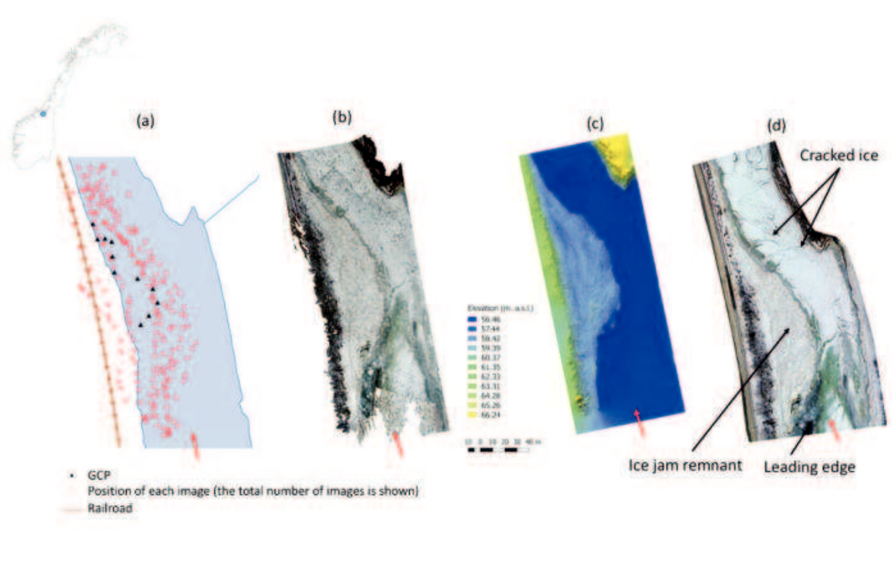
UAS are especially well-suited for the efficient generation of high-resolution geodata using cameras. The most promising approaches are derived from photogrammetric methods developed for remote sensing of satellite and aerial imagery using the Structure from Motion (SfM) method [11][12]. Advanced image processing methods create cm-accurate SfM geodata on river reaches ranging from 50 m to tens of km [4][11]. The most common types of UAS geodata are precise, high resolution digital elevation models (DEM) and orthomosaics, providing a level of detail previously not possible using satellite and aerial imagery.

UAS river surveys with SfM post-processing can provide reliable data with the added advantage of simple field deployment, and replication of measurements to reduce uncertainty and measurement errors [5]. Once completed, the geodata can be used to generate topographic maps [5][17], estimates of the river bathymetry [20] and sediment and habitat maps [19], investigate morphologic processes, including erosion and deposition [11][14], obtain surface velocity measurements [3][16] and many more.

UAS geodata is also being used increasingly in vegetation studies using multispectral cameras which provide maps of the normalized differenced vegetation index (NDVI) [18]. Key to the success of UAS in river geodata collection is their low cost: excellent results can be obtained from UAS for 5,000 € or less [2]. Due to their simplicity and inexpensive application, UAS surveying techniques now provide the opportunity to map and visualize riverine ecosystems and their changes over time. These new, time-resolved data provide resource managers, firms and researchers with a dynamic view of the river over time and space. Rivers, 2.0 will further

Figure 1. Survey work within National Environment Commission Bhutan project E-Flow at Punatsangchhu river for environmental flow assessment in regard to a future dam for hydroelectric power generation upstream. Manual survey with total station (top left and right) and echosounder (bottom left) in the future dewatered reach of Punatsangchhu I HPP. Use of a low cost UAS (center) in combination with ground reference points to build high resolution digital elevation model of both dry and submerged areas

Figure 2. (a) The position of the drone for each image (crosses) and the ground control points (triangles) overlaid on a digital map of the river section. (b) Dense point cloud of the same reach after processing the aerial imagery. (c) The georeferenced digital elevation model based on the point cloud. (d) The final, high-resolution orthophoto (5 cm/px) mosaic of the reach, showing both the ice jam to the left and an ice cover at different stages of formation [1]



evolve as advanced data processing techniques include existing data with UAS imagery using machine learning, creating new ways and means to study complex natural processes [8]. One of the most fulfilling aspects of UAS imagery and geodata is that it lends itself well to stakeholder involvement, presenting rivers "from above" is often a very effective way to share information and involve non-technical audiences in project planning [7].

Four examples of the use UAS imagery to study river landscapes and systems around the world are presented next.

Bhutan – Using UAS imagery to establish environmental flows (e-flow) for large hydropower

UAS imagery were processed using SfM to generate high-precision digital elevation models, which served as the basis for 2D hydraulic modelling for e-flow, also referred as residual flow, assessment on planned hydropower development in the Himalayas. Using a low cost UAS (DJI Phantom 3 Professional) reduced the manual survey effort to a minimum and increased the safety for the field crew as only certain areas of the river had to be entered. Spare parts for this system are available almost everywhere even in remote regions such as Bhutan.

Norway – River Ice Assessment using SfM and UAS

UAS images were used to create the first detailed maps of river ice forming in the Gaula River, Norway. Figure 2 shows the steps in the processing of the collected data. The resulting map includes features which are nearly impossible to collect using traditional ground-based surveying methods, including highly-detailed regions of cracked ice and a clear separation between the newly formed river ice and an older ice jam remnant.

Thailand – UAS for climate resilience monitoring of ecosystem-based watershed management

This project was part of the climate resilience monitoring of nature-based hydraulic structures and artificial wetlands in a Tha Di river, including flood protection and agricultural uses. It used conventional RGB (red, green and blue) camera images as well as Near Infrared (NIR) imagery to create high-resolution 3D maps of the river and surrounding vegetation. Figure 3 shows the position of the UAS image and the reference ground control points used, and Figure 4 shows

Figure 3. The Results of the 3D NDVI surface model. UAS image positions as well as the reference ground control points are also shown. The final model used a total of 284 multi-spectral (RGB, NIR) images [6]

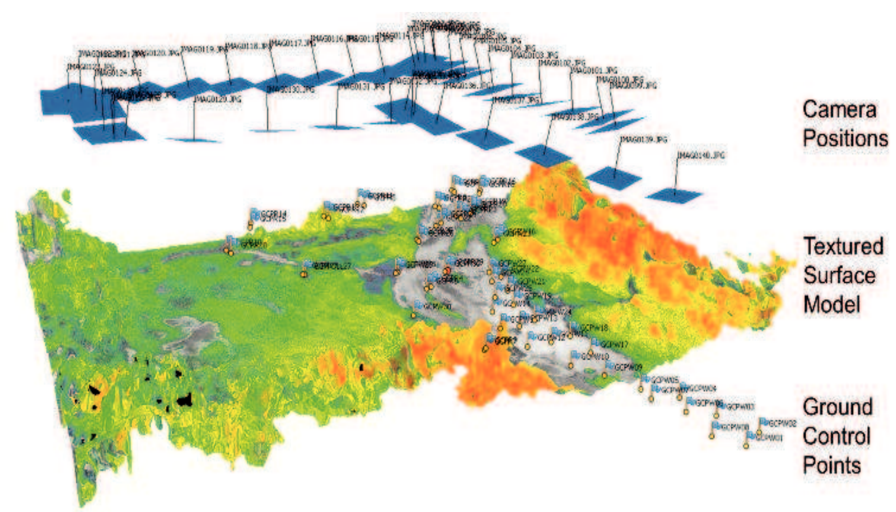


Figure 4. Left: NIR orthoimage of the nature-based living weir (red box) and surrounding vegetation with 5 cm/px resolution. Plants with higher activity are bright red, low activity green, and the river are shown in graduated grayscale [6]

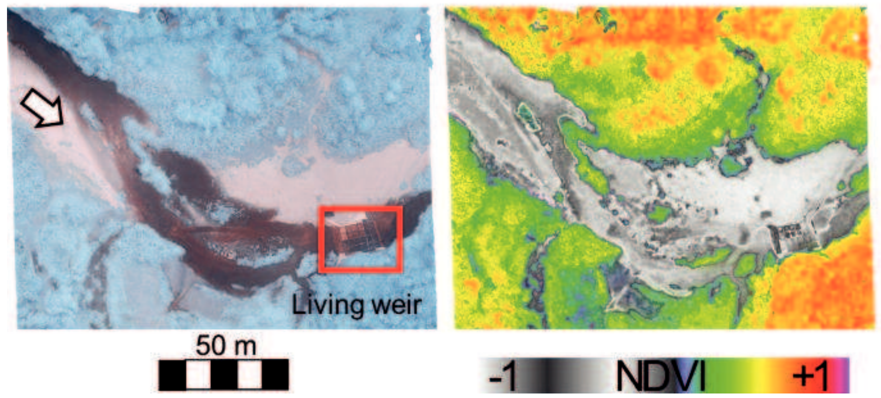
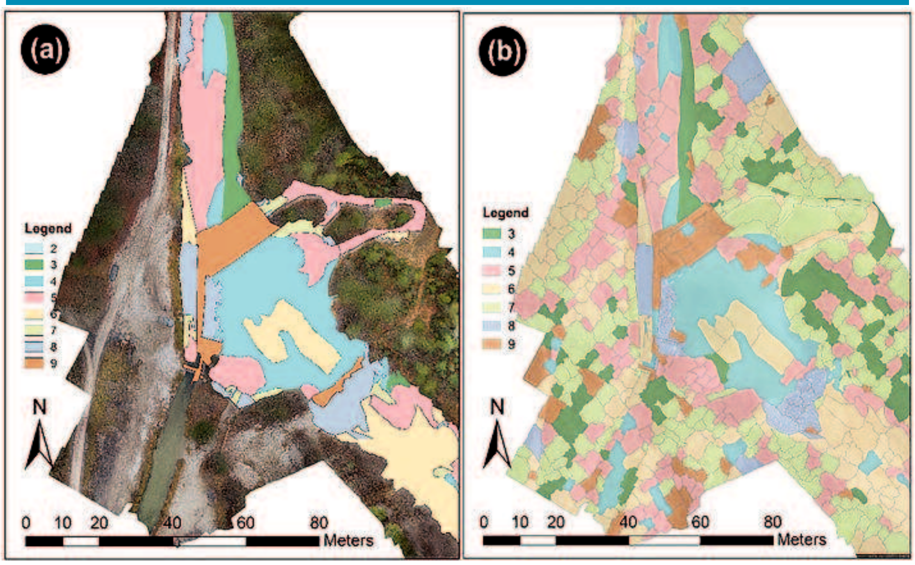


Figure 5. (a) A high-resolution ortho image was used in conjunction with standard terrestrial mapping methods to produce a substrate map. (b) An automated, object-based image classification method produces nearly identical results, with the added advantage of including regions not taken into account using the standard substrate mapping method [10]



the high-resolution vegetation map generated from these images.

Germany – Automated UAS-based river substrate mapping

Creating accurate maps of the river substrate is a challenging and expensive task because of the difficulty of field work data collection. Areas with a certain dominant substrate size [9] (rock (9), boulders (8), large stones (7), small stones (6), large gravel (5), medium gravel (4), fine gravel (3), sand (2), silt/clay/loam (1), organic material/detritus (0)) are mapped. Inspired by classical satellite remote sensing methods to classify land use, we developed new methods for using high-resolution UAS imagery in a Germany river to automatically classify and map the river substrate. Figure 5 shows side by side the high-resolution ortho image that was used in conjunction with standard terrestrial substrate mapping and the substrate map developed using the same ortho imagery obtained with a drone and an automated, image-based classification method.

Conclusions and Future Outlook

UAS provide an easy, safe, and cost-effective tool to collect river geodata in the age of Rivers 2.0. The variety of sensors is increasing, and the advent of more advanced data processing methods will continue to expand the use of UAS as low-cost remote sensing tools for river landscapes. We are especially encouraged by the latest results using machine learning algorithms in conjunction with the widespread availability of GPU image processors. Current UAS geodata include high-resolution point clouds, multispectral orthoimagery and digital elevation models. These data are not the final products; they can be processed to generate additional data products, such as NDVI maps to study vegetation, or maps documenting ground surface changes to study erosion and sedimentation. One limitation of many UAS is the use of ground control points (GCP) to correct for positioning errors during data collection. However, the use of high precision GNSS (Global Navigation Satellite System) in other fields such as self-driving cars has led to a massive decrease in the cost of GNSS receivers. Currently, consumer-grade UAS with cm-precision geopositioning can be purchased for around 5.000 €. This represents a tenfold reduction in the cost of such systems over the last five years. We believe that the use of UAS for river geodata collection has not yet reached its peak, and that affordable precision-GNSS will usher in another expansion phase of this field. The River 2.0 paradigm involves the transition from static, low-resolution geodata to the development and use of dynamic, high-spatial and temporal resolution geospatial data. Costs for large, time-resolved datasets are forecasted to decrease, and the simple deployment of UAS will lead them to becoming a standard surveying tool. Indeed, we believe that the coming years will see the transition from low to high resolution, and the change from annual, static data representations to seasonal or monthly dynamic maps; we call this transition “orthomotion”. The evolution of UAS technology has already made its mark on river measurements and mapping, by making field work more accurate, less expensive, faster and less dangerous. Welcome to the age of Rivers, 2.0. ■

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