Photogrammetry Aids River Restoration

Structure-from-Motion photogrammetry and GIS are being used to chart the success of a river restoration project in Northern England.

Many of the world's rivers are degraded as a result of modification of their flow regimes. This modification ('regulation') results from the construction of impoundments such as dams and weirs, as well as the water abstractions and tributary diversions that often go hand in hand with impoundment. Flow regulation affects the transfer of sediment downstream and, as a result, natural habitat-forming processes are compromised. These processes are important for aquatic organisms, so changes resulting from flow regulation affect the ability of rivers to support functional and diverse ecosystems.

Restoring Rivers

Recognition of the damage caused by flow regulation has led to the widespread growth of river restoration. Restoration can take many forms, but an overall guiding philosophy is that of restoring habitat-forming processes.

The River Ehen is fed by Ennerdale Water – an important water supply reservoir – with lake levels and the volumes of water released to the Ehen managed to help ensure that local and regional water demands are met. The Ehen supports some rare and important species of fish and invertebrate and, for the last ten years or so, the Environment Agency, United Utilities, Natural England and the Universities of Aberdeen (Scotland) and Lleida (Catalonia) have been working in partnership to help ensure that flow regulation does not compromise the river's ecological health. This partnership has involved various catchment management initiatives designed to improve habitat conditions in the Ehen, and most recently it has led to the reconnection of a formerly diverted tributary (Ben Gill). This reconnection aims to restore the natural conveyance of sediment from Ben Gill to the Ehen.

New Channel

Ben Gill naturally discharged to the Ehen a short distance downstream from the weir. However, it was diverted from its natural course in the 1970s to route water to the lake in order to increase storage. This diversion has meant that for the last 40 years Ben Gill has been unable to deliver its water and sediments to the Ehen. The result is that, in the section close to the weir, the Ehen has become unnaturally stable (in terms of flows, fluxes of sediments and bed mobility). To start addressing this problem, in 2014 a new channel was dug to reconnect Ben Gill to the Ehen. The new channel is around 300m long and follows the natural course of the stream.

We have been using Structure-from-Motion (SfM) photogrammetry to track how the new channel has evolved in response to a series of floods. We have been monitoring the topographic changes in the new channel that result from these floods, as well as assessing the volumes and sizes of sediment now being delivered to the Ehen as a result of the reconnection. This information is being linked to field-based assessments of sediment transport in the Ehen, to assess the degree to which more natural and dynamic sedimentary processes are returning to the river.

Monitoring Surveys

The work has involved periodic aerial photographic surveys of the new channel, when it was in a dry state, using a drone (DJI Phantom UAV), with successive digital elevation models (DEMs) produced from the image-based point clouds. DEMs produced from successive surveys were used to assess topographic and sedimentological changes associated with flood events. One of the things we were particularly interested to do was to assess the utility of low cost, consumer grade cameras for this type of work, where accuracy and confidence in model output are of critical importance. To this end we spent a considerable amount of time calibrating the camera (GoPro Hero 3+, 11 MP) and testing various flight altitudes to optimise image resolution and overlap. We also installed 196 Ground Control Points (GCPs) along the channel (covering an area of 0.06 km^2). One third of the GCPs were used as checkpoints (to assess the quality of the point clouds), while the remainder were used to control the photogrammetry.

Images were captured at one second intervals, with repeat passes giving around 1100 images for each aerial survey. Nine surveys have been conducted in the first two years of the new channel's life. Images were post-processed using AgiSoft PhotoScan, to produce an orthophoto and a high-density point cloud for each survey. The point cloud consisted of many millions of points (30-40 million), resulting in a point density that varied from 1400 to 2200 per m^2; image resolution was 2-3cm per pixel. From a computing perspective, such dense 3D point clouds are highly demanding to handle so 2.5D raster files were produced from the point clouds to help with processing and analysis of the topographic data within Esri ArcMap. To produce DEMs for each survey, point clouds were decimated using the geostatistical toolkit ToPCAT2, available in the open source Geomorphic Change Detection software (http://gcd.joewheaton.org/). The minimum elevation in each cell was used to create the DEMs.

Model Accuracy

Because we were interested in assessing the utility of the GoPro, we paid careful attention to errors when constructing the DEMs. As an example of error, some statistical parameters are given in Table 1 for the first three DEMs we produced. The table indicates that model accuracy (3D) was around 5cm or less. This value was extremely reassuring as it is smaller than the size of the sediment in the channel; in turn, this error means that we can be very confident in the assessment of how the channel is changing.

Comparing DEM’s

By subtracting successive DEMs, we were able to assess any spatial patterns in the loss (scour) or accumulation (fill) of sediment along the channel that occurred between surveys. The estimated accuracy of each DEM allowed us to compute minimum levels of detection which we used to attach confidence to these assessments of change. Changes that are similar to the minimum level of detection are considered uncertain, since they could merely represent the propagated error of the two DEMs being compared, rather than real topographic change. In the output from these analyses, areas where estimated changes are below the minimum level of detection are left transparent, while coloured areas represent locations where changes were greater than the minimum level of detection. The models allowed us to estimate net volumetric change in the channel between successive surveys – a change which represents the minimum amount of new sediment delivered to the Ehen.

Measuring the Bar

Sediment delivered from Ben Gill initially accumulates in a gravel bar at the confluence with the Ehen. Within six months this bar grew from zero (prior to the reconnection) to more than 30m long and 5m wide, and is now made up of more than 150m^3 of sediment. We are now using photogrammetry to assess volumetric changes in the bar, and by coupling this with hydraulic models, determine the flow discharges which dictate how the sediment that makes up the bar is mobilised and conveyed downstream within the Ehen. In fact, it is already functioning as a local sediment source, with new bar features developing further downstream in the Ehen as a result of material originating from the confluence bar. These features, consisting of loose, mobile gravel-sized material, are a critical element of the habitat of the fish and invertebrate species that sit at the heart of the restoration work. Additionally, these new features modify the morphology of the river channel, helping to generate the varied flow conditions which help support increased biodiversity.

The restoration work in the River Ehen involves the reconnection of a whole sub-catchment (Ben Gill) to a main-stem river – a unique example of a system scale restoration project. Our photogrammetric work is proving invaluable, as it is yielding quantitative estimates of the amount of sediment now being delivered to the Ehen following the reconnection of Ben Gill. Because of the attention paid to error analysis, we can be confident in these estimates, and more broadly that the restoration project is beginning to achieve its objective of restoring processes in the system.

References

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