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STRUCTURE FROM MOTION WITH UNMANNED AERIAL VEHICLES

A Best Practices Guide for New Users

Tips and tricks to help you get started using low-cost unmanned aerial vehicles to generate accurate three-dimensional models for stream channels and drainage ditches

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Design and placement of ground control points for accurate output

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SITE PREPARATION

It is well recognized that ground control points (GCP) improve the accuracy of produced surfaces. Various studies have been conducted to determine the number of GCP necessary to achieve reasonable accuracy. To generalize this literature, accuracy increases with the number of GCP. However, the law of diminishing returns applies, and there is a point at which the effort to obtain additional GCP is not justified by the marginal increase in accuracy of the output.

Separate from ground control points are ground check points. Whereas ground control points are used during processing to fit the surface accurately, ground check points are used in post-processing to evaluate the accuracy of the produced surface. In practice, the site preparation and collection of coordinates for both control and check points is the same. The distinction is relevant only during processing and evaluation.

TIPS FROM LITERATURE

GCP should be distributed uniformly across the site, but not in linear patterns (Smith et al., 2016). With sufficient coverage, the pattern itself was shown not to affect the final product (Clapuyt et al., 2016); however, ill-distributed GCP were shown to effect the georeferencing of the final product (Goetz et al., 2018). Harwin and Lucieer (2012) recommend a spacing of 1/5 to 1/10 of the flight altitude as a rough estimate for distribution of GCP, with tighter spacing as topography increases.

GCP should extend beyond the region of interest to avoid edge effects (Jaud et al., 2016). If a large number of well-distributed GCP is not possible, the second best option is placement of GCP on different sides of the imaging zones, seeking to maximize the appearance of GCP in collected images (Shahbazi et al., 2015). Height of GCP should also be considered if the study site has changing topography. Harwin and others (2015) recommended a variation of 10% of the flight altitude. Ajayi and others (2018) performed reconnaissance flights to determine where GCP should be placed before beginning a field campaign.

GCP size and appearance can affect detection within imagery. Natural targets often lack strong contrast, limiting their use as GCP (Eltner et al., 2016). GCP can be custom fabricated (e.g., Verma and Bourke, 2018), or automatically created by analysis programs (e.g., Agisoft). Smith and Vericat (2015) recommend scaling the size of GCP relative to the spatial resolution of the sensor; however, larger targets lead to greater error in exactly defining reference points (Smith et al., 2016). If GCP are installed on a quasi-permanent basis, maintenance of vegetation may be warranted to maintain visibility (Duró et al., 2018).

FLIGHT PLANNING

Camera selection will affect the accuracy of the final product. Low-cost unmanned aerial vehicles (UAV) have integrated cameras, but other platforms offer the ability to custom equip the aircraft. Generally speaking, literature discourages the use of cameras with rolling shutters (e.g., GoPro) and zoom lenses. Although a relatively wide angle lens is desired, the radial distortion must be within acceptable limits.

Freely-available flight apps for UAV offer a built-in three-dimensional flight option. Generally, these flight plans resemble a hashtag owing to their pattern of both N-S and E-W flight lines. Literature recommends high levels (in excess of 80%) of side and front lap between successive images. An increased number of images improves the accuracy of the output surface, however, the increase in accuracy is not linear, and should be weighed against the increased processing time.

TIPS FROM LITERATURE

Over and underexposure can lead to errors during point cloud generation. Rosnell and Hankavaara (2012) recommend use of cameras with a high dynamic range and large physical pixel size. The larger the pixel size, the higher the amount of light, and thus the higher signal-to-noise ratio. Image collection should be conducted at the highest possible signal-to-noise ratio to preserve processing options (Eltner et al., 2016).

Oblique imagery has been used to supplement imagery collected at a single altitude. Bemis and others (2014) suggest differences in angle of convergence be limited to between 10 and 20 degrees, as larger angles decreased the accuracy of the output surface. However, Harwin and others (2015) suggest there is no added benefit to oblique imagery when ground control accuracy is high.

For sufficiently large study sites, changing sun angles may create issues with shadowing, thus flight time should be a consideration. Freely-available flight apps for UAV report the estimated time of flight. For flight times exceeding 30 minutes, conducting the mission in stages over multiple days at the same time of day may prove more beneficial (Bemis et al., 2014). For areas where the mission environment is sufficiently difficult to preclude frequent, but necessary flight, one option available is the use of static arrays of cameras. Although not structure from motion, this effort offers many of the same end products and has been successfully used in even harsh environments (e.g., Mallalieu et al., 2017). However, Eltner and others (2016) noted that research gaps still exist for the use of time-lapsed structure datasets with current practices.

DATA PROCESSING

Processing of UAV imagery into three-dimensional surfaces can be performed with both desktop and cloud-based solutions. All processing platforms have benefits and drawbacks. Cloud environments typically produce products rapidly, and reduce end-user skill, computing power, and storage capacity requirements. However, the lack of user intervention can be frustrating for more advanced users with more stringent needs for control. Cloud environments can also be less expensive than desktop software, but this can be a case of cost matching functionality.

Every choice made during the processing period can affect the final product, sometimes in unexpected ways. Generally, choices must be made regarding filtering and cloud density. The level of filtering required is dictated by the textural complexity of the study site. A balance must be achieved between preserving fine detail and reducing noise. Likewise, a balance between cloud density and processing time must also be identified. Increasing the cloud density leads to increased processing time. Depending on the processing time and frequency of data collection, it may be impractical to conduct regular missions over larger areas and process the data at high cloud densities if time is of the essence.

TIPS FROM LITERATURE

The majority of ground filtering algorithms were designed for LiDAR data, and not UAV imagery. The performance of these algorithms decreases with higher point densities; high point densities are often associated with vegetation in study sites (Serifoglu Yilmaz and Gungor, 2018). In fact, vegetation is a key source of error in most published studies. Vegetation is problematic because of its differing appearance from different view angles (Eltner et al., 2016). Vegetation results in systematic overestimation of surface height (Hugenholtz et al., 2013). Seasonal changes in vegetation can also reduce the ability to conduct time series analysis of output surfaces (Hamshaw et al., 2017).

One benefit of UAV is the high resolution imagery provided from low altitude flight. Selecting lower-resolution processing, while reducing the resolution of the three-dimensional model, does not impact the output resolution of the mosaic (Bemis et al., 2014). However, Eltner and others (2016) noted that down-sampling of imagery could lead to underestimation of relief.

Although programs vary in their presentation of filtering and cloud density processes, the basic principles of the structure from motion workflow are consistent. Smith and others (2016) presented a thorough, understandable explanation of the steps which must be undertaken to create three-dimensions from basic two-dimensional imagery. Serifoglu Yilmaz and Gungor (2018) offer a thorough discussion of filtering algorithms. Researchers (e.g., Jaud et al., 2016; Sona et al., 2014) have conducted fundamental tests of available software packages, both free and proprietary, and summarized strengths and weaknesses.

MODEL INCORPORATION

Use of three-dimensional surface outputs to replace intensive field campaign remains a goal of the scientific community. To the extent that the data produced are accurate, the UAV is capable of providing necessary input data for hydraulic models in fluvial basins. The UAV have proven useful for not only improving the resolution of system geometry, but the images themselves are useful for providing context to the systems. This includes identification of present vegetation, which can be useful in assigning friction coefficients (e.g., Manning's), as well as characterization of upland condition and potential sources of incoming overland flow.

To date, challenges remain in systems where more than low flow conditions exist. However, these challenges are experienced by competing technologies, and the community currently has workarounds that provide supplemental data for submerged areas. Although not as straight-forward as empty channels, characterization of shallow-water bathymetry is possible under the appropriate conditions.

Another limitation of the three-dimensional surface is characterization of undercut banks. Due to the nature of the overhead view, the UAV may be limited its ability to properly represent these areas; however, this problem is not unique to UAV and is also problematic in tradition survey. If an initial inspection of the fluvial system reveals significant undercutting of the bank(s), proper documentation is necessary in any hydraulic or channel evolution model that uses geometry generated from the three-dimensional surface.

TIPS FROM LITERATURE

Hydraulic, sediment and channel evolution models are relevant tools for flood hazard prediction, sedimentation engineering decision taken, stream restoration and other areas of professional exercise. The characteristics of the landscape and geometry of the channel in evaluation are a critical factor in the proper performance of the model and results analysis (Reali, 2018). Images acquired with UAV are seen as a good alternative data sources to obtain spatial data that represent the terrain surface with a high level of detail (Pádua et al., 2017).

There is very limited information that relates the use of UAV on hydraulic or channel evolution modeling. Mourato and others (2017) state that the most critical factor that limits the use of geometry generated from UAV or LiDAR images on hydraulic models is tied to the presence of highly vegetated segments along the river banks of the surveyed area, as these segments of the image can be inaccurate for the vegetation can't be entirely filtered out. Reali (2018) emphasized the need to properly develop a stream bathymetry in deep areas before advancing any modeling effort. Different remote sensing tools are limited to represent the underwater topography of the aquatic system. Some attempts to solve this problem are available in literature (e.g. Zinke et al., 2012), but there is still a potential research need for development of this capability in UAV technology.

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