Methods for processing and analyzing UAV-retrieved Lidar and RGB data covering selected areas in Accra

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METHODS FOR PROCESSING AND ANALYZING UAV-RETRIEVED LIDAR AND RGB DATA COVERING SELECTED AREAS IN ACCRA

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1. INTRODUCTION

A main objective of the Climaccess project is to analyze how extreme rain will affect future urban flood patterns in Accra. Within the project, several methods have been developed and tested for identifying and mapping high-risk flood locations on both city-wide and local scale. Integrated in the methods is the creation of hydrologically correct, digital surface models which form the basis for the modeling of water flow and potential flood locations. While the methods used for city-wide flood modelling is described in a separate Climaccess technical report, the current report focus on the improved precision of mapping of flood prone areas in order to optimize the flood risk assessment at the local scale.

The report describes methods for generating high resolution digital terrain models (DTMs) featuring manmade structures (DTMb) suitable for hydrologic modelling using data acquired by a miniaturized Light and Detection Ranging (LiDAR) scanner and an RGB camera obtained by navigating Unmanned Aerial Vehicles (UAVs) over urban neighborhoods in Accra. The high resolution DTMbs can be used as inputs to a hydraulic/hydrological model covering the drone-surveyed areas in order to detect the exact location, extent and depth of local sinks.

1.1 Background

Topographic elevation data (Digital Elevation Models-DEMs) of low spatial resolution may introduce inaccuracies in flood modelling because meter-wide features of the ground conditions can create a critical difference in the simulated flooding (Leitão et al., 2016). Misrepresentation of bridges, tunnels, elevated roads, concrete fences, continuous walls, or embankments may result in fault simulations of the direction and amount of water flow, by neglecting their important downstream effects on urban water resources (Meesuk et al., 2015). Similarly, DEMs of low temporal resolution may constraint the potential of capturing dynamic alterations of urban microtopographic features that have a substantial influence on flood propagation patterns such as, construction or relocation of structures and infrastructures close to rivers, or vegetation removal (Brazier et al., 2015). Thus, to provide a realistic representation of terrain for flow modelling and consequently flood risk estimation, topographic data of fine resolution (< 1 m) is required.
In principle, UAV LiDAR technology or UAV-photogrammetry can be deployed over any flood-prone area to provide precise and cost efficient additional input to the city-wide flood models, thereby providing increased accuracy of the flood models where needed.

Many hydrological models are based on airborne LiDAR/RGB-derived DTMs that represent only the bare earth surface (Leitao et al., 2009) or Digital Surface Models that illustrate all the information of surface topography, but DSMs featuring terrain, buildings and other manmade features (DTMbs) can generate more realistic water pathways. The main challenge of point cloud data obtained by LiDAR scanners is their classification to ground, vegetation, buildings, noise, bridges and potentially geomorphologically important objects during floods. Most published algorithms for ground return classification utilise morphological-based (Zhang et al., 2003), slope-based (Vosselman, 2000) or triangular irregular networks (TIN) (Axelsson, 2000) filtering algorithms. Compared to a Lidar scanner, a typical camera onboard a drone cannot adequately penetrate the canopy in areas where highly dense low or high vegetation occurs. However, depending on the flight settings, we can retrieve reliable information regarding the surface elevation, in the absence of a UAV-Lidar system.

In this report a workflow for processing the acquired UAV LiDAR-derived point cloud data and UAV imagery using the Structure for Motion (SfM) method (Westoby et al. 2012) is presented. Four DTMbs of 0.3 m spatial resolution are produced for four different sites in the Greater Accra. A short description of the UAV-surveys set-up is also discussed. The suggested techniques have a strong application potential especially for optimizing urban flood risk assessment in areas where urban development is rapid and haphazard.

2. Materials

2.1 Study area

During the last century Ghana has been challenged by severe floods affecting over 3.5 million people and causing 567 losses of human lives (www.emdat.be.). The increased frequency of locally intense, short duration precipitation events in the Accra region coupled with poor urban planning and flaws in the drainage network have resulted in widespread devastating flash floods (Ansah et al., 2020). From 2015 to 2018 extreme rainfall events concurrent with the peak of rainy season, caused 164 deaths and more than 34,000 people were displaced with damaged properties. In 2019 only, Accra has experienced four severe flood events causing 29 deaths and 4,000 destroyed buildings highlighting the urgent need to better understand local flooding in order to deploy early flood-control measures. The selection of study sites exposed and vulnerable to flash floods was based on information collected from local politicians, planning officers, chairmen and board members of residents’ associations, transport workers.
In August, 2019 four aerial surveys were conducted using the UAV-Lidar and UAV-imagery system covering four selected test areas (see also the separate Climaccess technical report on field validation):

1) Santa Maria locality (16.7 ha) which is a consolidated, highly dense area close to the centre. The citizens have low to middle income and flooding has been reported to occur in key sections of roads close to a main road. The area includes a steep hill nearby the low-lying urban area (Figure 1).

2) New Legon Hills (Adenta district) which is a peripheral newly developed area, quite interior with a very poor road quality or non-existent roads. The citizens have middle-high income but the impacts of flooding were severe plausibly due to flood-prone outlet roads (Figure 2).

3) Campus of the University of Ghana (hereafter Legon Hall, 14.7 ha), located at the northeast of the centre of Accra, characterized as a very flat terrain. (Figure 3).

4) Okponglo area (25 ha) located in the city center surrounded by main roads and close to the Accra Sports Arena (Figure 4).

Figure 1. Illustration of the acquired high dense point clouds in Santa Maria. The point clouds are coloured by elevation.

Figure 2. Illustration of collected high dense point clouds in Adenta.
2.2. Description of UAV-platform

The applied UAV system consists of a LiDAR scanner (LiDARSWISS, Inc) onboard of a Matrice 600 Pro octocopter. The LiDAR system includes: 1) a beam LiDAR scanner (Quanergy M8); 2) an inertial navigation system (INS) that fuses data from an Inertial Measurement Unit and GPS data received by a Global Navigation Satellite System (GNSS) antenna in order to achieve real-time navigation, high precision positioning and attitude; 3) a SONY R10-C camera with 16mm lens; and 4) an integrated data storage unit. The scanner can measure and record the angles at which each pulse is emitted and receives the reflected pulse from the surface (“return”). The laser scanner has 8 laser beams and a vertical field of view equal to 20° (+3°/-17°), resulting in high vertical resolution. The point density (PD) of Lidar returns is a function of the: flying altitude above the ground (h in m), flying speed (u m/s), scan angle (theta degrees), frequency of laser pulse emission (PE Hz), surveyed area rate As=2 u h tan(theta) and roughness of target scanned.
(PD= PE/ As in points/m²). The mean point density of the point clouds retrieved by the UAV-surveys is 50 points/m² (max 400 points/m²). The heading accuracy of the laser scanner is 0.10 degrees, and the pitch/roll accuracy equals to 0.05 degrees with an overall accuracy (RMSE) less than 0.03 m. A Trimble Real Time Kinematic GNSS Base Station was also used to provide additional overhead of communicating with the INS to correct the GPS signals after the flight, offering greater robustness and absolute accuracy in the range of just a few centimeters.

2.3. Preparation of UAV-survey in an urban context

The legal framework for the UAV operation is typically determined based on the weight of the UAV, range, as well as the purpose of the flight. All the regulations for UAV operation were followed to minimize risks to people and property both in the air and on the ground. Particular concerns included privacy, data protection and public safety. Permissions for operating UAV in the four selected sites have been provided by the local authorities and local notification to the police and land owners was employed in order to prevent conflict with other airspace users or the general public, and to allow monitoring of the flight. Two launch areas were located in rooftops of buildings (e.g. Figure 5) and two other in park areas and were all far away from roads and other buildings. The access of citizens to the launch areas was restricted to secure their safety. The drone use was the responsibility of the UAV pilot who had pilot license granted by the Danish aviation authorities. Before the aerial campaign, all sites and take-off locations were visually inspected to assess the challenges that local topography (e.g. hilly sites, towers, tall buildings) and environmental conditions (e.g. windy conditions) may introduce to the UAV operation. The flights were performed 60 m above the ground with a flight speed of 5 m/s, an 80% forward overlap and 65% side overlap specifications. The flight horizontal distance was limited by the pilot’s visual line of sight (VLOS).

A detailed description of the experimental set up including: the flight planning, the connection of the LiDAR and the RGB camera with the drone, the set-up of the GNSS base station for correction of drone position, instructions for operating the drone and the preprocessing of the raw LiDAR data to point clouds, was shared within the project to allow future replication of aerial campaigns in other areas of interest.

Figure 5. Take off point in Adenta district.
3. METHODS

3.1 Point Cloud Data Processing

This section describes the processing of point clouds (e.g. Figure 6) for generating high-resolution Digital Surface Models including ground (bare-earth surfaces) and buildings (DTMb), but excluding other surface features such as vegetation, pedestrians, and vehicles. The generation of the DTMb involves:

- assembling the flightpaths into one point cloud for each study area;
- alignment of flightpath for each surveyed site;
- de-noising of the point clouds;
- classification of the UAV-LiDAR point clouds into terrain, vegetation, buildings and other man-made features, using various image-processing techniques like the morphological (MM) and triangulated irregular network (TIN) methods. Removing non-ground points from LiDAR datasets has proven to be a challenging task, especially in densely vegetated areas, steep terrain and highly varied terrain like urban areas.
- after-classification removal of of ground and non-ground points including objects like trees and bridges to avoid water flow blocking in the simulations. The remaining points are interpolated (e.g. using the inverse-distance weighting method) in order to rasterize the point clouds and generate DTMbs.

Figure 6. Screenshots of the point clouds highlighting the level of detail of data.

Different approaches are applied and evaluated based on the methods implemented in the software products, ArcGIS Pro (ESRI, 2020) and LasTools (Rapidlasso GmbH) the latter of which is a stand-alone software product but also included as a toolbox in ArcGIS Pro- and Global Mapper software (Blue Marble Geographics, 2020). The main structure of the workflows in ArcGIS Pro and LAStools is similar: First
duplicates and noise are removed from the dataset and then ground and building points are classified separately using the TIN approach. The tools included in LAStools have more optional parameters compared to the ArcGIS Pro that may have significant effect on the point cloud classification. The Global Mapper was utilized to classify the point clouds using the MM approach. The effectiveness of the different algorithms to classify the UAV-Lidar derived data is evaluated by comparing the percentage of points grouped to different classes with the respective amount of points manually classified.

3.1.1 The TIN method using LAStools

The LAStools software consists of a suite of tools for filtering, tiling, rasterizing, triangulation and converting LiDAR data (Figure 7).

A detailed description of the tools can be found in the LAStools website. Here we present the main steps and configuration that were applied to produce the DTMbs:

1. **LasDuplicate**: Removes all duplicate points. In the default mode those are xy-duplicate points that have identical x and y coordinates.

2. **LasNoise**: The tool attempts to find points that have only few other points in their surrounding 3 by 3 by 3 grid of cells with the cell that the respective point falls into being in the center.

3. **LasThin**: The thinning algorithm places a uniform grid over the points and within each grid cell keeps only the point with the lowest (or ‘-highest’) Z coordinate. W kept ‘-random’ points I to specify a ‘-seed 232’ for the random generator.

4. **LasGround_new**: This is a tool classifies LIDAR points into ground and non-ground points. The parameter “step size” defines the average building size, allowing the removal of most buildings. Search window sizes from 5m to 25 m at 5 m interval were tested to optimize the number of ground points. For ground classification, the 5 m step size was more effective compared to the 25m cell size that was more efficient to classify buildings. For UAV data we should choose the ‘-all_returns’ instruction. The ‘-bulge 1.0’ parameter specifies how much the TIN is allowed to bulge up when including points as it is getting refined. The maximal offset in meters up to which points above the
current ground estimate get included were set equal to ‘-offset 0.1’. Calculation of the parameter “compute height” was also selected.

5. **LasClassify**: This tool classifies buildings and trees. The TIN approach was more effective in classifying the building points using a step size equal to 25m but it generated less ground points than the actual exist and could not identify any vegetation points. Different values of maximal standard deviation for planar patches (‘planar ’ for roofs and ‘-rugged ’ for trees) were tested to optimize the number of building and tree points. The ‘-ground_offset ’ was set equal to 1.8, 1.7, 1.6 and 1.5 m.

The different parameter settings for this tool can be visually evaluated (Table 1). Figure 8a and 8b show two screenshots of the classified point clouds using two different settings: a) building planarity 0.2, tree ruggedness 0.4 and ground offset equal to 1.8 or 1.7m and b) building planarity 0.1, tree ruggedness 0.4 and ground offset equal to 1.6 m. A comparison of the results indicates the significance of choosing the most suitable filtering thresholds to optimize the classification of point cloud data.

![Figure 8](image)

**Figure 8.** Screenshots illustrating point cloud data classifies into ground, high vegetation and buildings, using different thresholds of roof planarity equal to 0.2 (left) and building planarity equal to 0.10 (right).

In the second case, more building points were falsely classified as high vegetation (red cycle).

### 3.1.2 The TIN method using the ArcGIS Pro approach

The standard method in ArcGIS Pro rely on filtering of the point clouds. Figure 9 shows the different tools used in the workflow from an unclassified to a classified point cloud. The tools filter the point cloud and successively assign class codes to the points in the cloud. At the end of the workflow the point cloud are classified as either "overlap", "noise", "ground" or "building", and the remaining points are left unclassified. A detailed description of the tools is available online in the manual of the ArcGIS software. The main characteristics of each tool are presented below:

- **Classify LAS Overlap**: The points in an overlap zone (a zone where two or more flight lines cover the same area) are marked as overlapping if the distance between points is less than the average distance between points in the dataset.
**Classify LAS Noise:** The next step is classification of noise. Returns from flying birds, haze, water bodies and reflective mirrors can distort the z-range of the points surrounding that location. Identifying these points as noise will allow them to be filtered out from display and eliminated from analysis. Several custom defined parameters will control how “aggressive” the noise filter performs. The method used in this tool is ISOLATION of points within a neighborhood of 3 x 3 meters.

![Figure 9. The processing steps for method in ArcGIS Pro.](image)

**Classify LAS Ground:** The selection of method (three are available) allows different tolerances for slope variation. The STANDARD option is chosen since it has a tolerance for slope variation allowing it to capture gradual undulations in the ground's topography.

**Classify LAS Building:** The selection of method (three are available), allows different tolerances for outliers. The AGGRESSIVE method allows a relatively high tolerance for outliers. The STANDARD method allows a relatively moderate tolerance for irregular points. The method used here is the STANDARD classification. An example of classified Lidar points is illustrated in Figure 10.
Figure 10. Example of classified Lidar points clouds into buildings and terrain using the ArcGIS Pro method.

The tools in both ArcGIS Pro and LAStools provide specific interpolation methods to convert point clouds into raster format, and options for defining cell size of the output raster. In all cases, the input point clouds in LAS format should be classified to ground and building points including boundary walls before rasterization (Figure 11a). We can choose the the **LAS Dataset To Raster** tool in ArcGIS Pro or the LAStodem method in **LasTools** with a step size for interpolation equal to 0.3 m (Figure 11b). The interpolation type is Binning and cell assignment is Average. When the cell assignment is chosen to be the minimum, the buildings are blurred in the edges.

### 3.1.3 The morphological approach using the Global Mapper

To detect ground points we initially followed a two-part process that removes points that are likely non-ground based on the local terrain slope and the range of elevation values in the dataset (Vosselman, 2000), and then the remaining points were compared to a modeled 3D curved surface inside a series of grids. The parametrization of the algorithm included alteration of the values of the bin size and the allowed height change from the local averaged minimum, at which points are removed from the ground classification in order to model a curved ground surface. To classify buildings and trees we applied a morphological-based algorithm which is based on the points’ relationship to a calculated best-fit planar surface inside each bin of Lidar data (Global Mapper software). The required minimum height above the ground for a possible building or high vegetation point, was set equal to 1.7m. Bridges were detected following a segmentation method introduced by Sithole and Vosselman (2006). Point cloud data representing high vegetation, bridges, telecommunication towers and cars are excluded from the rest dataset (See example in Figure 12). The remaining data are interpolated using the Inverse Distance Weighting method in order to rasterize them and produce the DTMbs at 0.3 m high spatial resolution using the MM method (Figure 13 and 14).
3.2 From UAV-derived RGB images to a digital surface model (DSM)

Based on UAV-photogrammetry, 3D surface information in the form of point clouds can be generated from different viewpoints of overlapping photos taken by a digital camera and using a SfM approach (Westoby et al., 2012) to generate topographic data with an accuracy of ±0.5 m approximately. Images are inspected for characteristic tie points that are detected in more than one image and based on these points the images are aligned in the form of a point cloud using the bundle block adjustment algorithm (Triggs et al., 2000). The spatial resolution of the 3-D elevation model is increased and triangulated using the TIN method, which is then rasterized.

In this section we describe a workflow for processing RGB images obtained by a UAV-camera system in order to generate high-resolution Digital Surface Models without excluding other features such as vegetation, pedestrians, and vehicles. The images are processed using the Metashape software (AgiSoft PhotoScan Professional, 2016) where the main photogrammetry tasks are: the bundle block adjustment, the point cloud generation, and filtering in order to generate an orthomosaic. Ground control points in the LiDAR dataset were used to reference the coordinate positions of the SfM point-cloud data. A detailed description of the image processing can be found in the manual of Metashape software.

3.2.1 Workflow

1. Load the images: “Workflow -> Add Photos” and then select all images, right-click on one and choose “Estimate Image Quality”. Switch to the ‘Detail’ view in the Photo pane to see the quality score from 0 to 1. Images with scores less than 0.5 should be removed.

2. Load Camera Positions: Setting the coordinate system provides a correct scaling of the model. With geotagged photos, the coordinates are usually Lat/Long (in degrees); use the convert tool in the “Reference” panel to convert to the preferred coordinate system.

3. Load the associated camera lens distortion profile: “Tools -> Camera Calibration” Optical (barrel) distortion will be corrected using the common third degree polynomial approach. If the information about GPS/INS offset with respect to the camera itself is available it should be used as input on GPS/INS Offset tab of camera calibration dialog from Tools menu.

4. Align the images: This step finds image pairs with overlapping scenes. Select Generic, or Reference if the images are geotagged. “Workflow” ⇒ “Align photos”.

5. Place the markers: To be able to follow the guided marker placement approach the geometry needs to be reconstructed. Select Build Mesh command from the Workflow menu and specify “Surface Type ⇒ Height Field” and face count: 200000. When geometry is built, visually inspect an image where a Ground Control Point is visible in Photo View by double-clicking on its icon on the Photos pane. Place the markers by double-clicking one of the images with a on the image from the “Photos” window and
click on “Create Marker”. Find the same GCP on one of the other images, and select “Place Marker” with the same “Point” number of the former image.

6. Input Marker Coordinates: In Import CSV dialog indicate the delimiter according to the structure of the file and select the row to start loading from. Once all GCP has been marked on all images the marker coordinates must be defined Select (Import) in the “Reference” panel.

7. Optimize camera alignment: Prior to optimization it is also possible to remove the points with the highest reprojection error values using corresponding criterion in Edit Menu → Gradual Selection dialog. Go to the “Edit” menu and select “Gradual selection“. The first option is “Reconstruction uncertainty“ where it can be set equal to 10. Then to optimize the alignment of the cameras click the wizard’s wand icon.

8. Bounding box: The area that needs to be modelled must be included in the selection box using the tools for rotating and scaling the box to fit.


10. Build Mesh: “Workflow -> Build Mesh”. Set Surface type to Height field, and select the dense point cloud as Source data. The Face count can be set to Medium, and the Interpolation Enabled.

11. Build Texture: Select Build Texture from the Workflow menu. For Mapping mode select Orthophoto and for Blending mode Mosaic.

12. Build DEM Metashape: Digital elevation model is generated based on the dense cloud option. Color calibration: If the lighting conditions have been changing significantly during capturing scenario, it is recommended to use 'Calibrate colors' option.

13. Build Orthomosaic: Texture mapping can add photographic detail to the 3D surface based on the original images. The orthomosaic is generated by correcting the individual photographs for relief distortions and projecting them onto a planimetric surface with a real-world coordinate system.

14. Export DEM and Orthomosaic: “File -> Export DEM” Select Export DEM → Export GeoTIFF/BIL/XYZ command from File menu. Similarly, “Export Orthomosaic” → Export JPEG/TIFF/PNG command from File menu (Figure 15). If the exported area is large it is recommended to enable Split in Blocks feature.

4. RESULTS

4.1 Generated hydrological corrected terrain models (DTMbs)

By comparing the performance of the three filtering approaches in the four sites it was found that the TIN approach was more an appropriate algorithm for classifying ground points in the hilly site of Santa Maria, while the MM filtering was more efficient for classifying the point cloud dataset in the rest flat terrains. The results obtained by the LAStools method did not differ significantly from the results obtained by the ArcGIS Pro method. The main structure in the workflow is almost the same: First removing duplicates and noise from the dataset and then classify ground points and building points separately. In general, the tools
included in LAStools have more optional parameters than the tools in ArcGIS Pro. Especially the different parameters in the tool LasClassify, where parameters such as ground offset and search area size seem to have significant effect on the classification of buildings.

In Santa Maria the classification of ground and high vegetation was achieved by tuning the TIN model at: a 5m step size, a building planarity equal to 0.2 and a value of tree ruggedness equal to 0.4, that over performed the MM approach. In the MM approach the optimal set of parametrization that led to a more accurate classification consisted of: a minimum height above the local average minimum elevation equal to 0.3 m, and a bin size was equal to 0.5 m. For the morphological filter the optimal RMSE building planarity was 0.2 m with the vegetation distance being equal to 0.3 m.

![Figure 11. a) DTMb at 0.3 m spatial resolution for the Santa Maria site (upper) and b) classified point clouds to ground, and concrete manmade features (lower).](image-url)
Figure 12. Digital Surface Model (DSM) of the Legon Hall site including high vegetation features (left) and hydrological corrected elevation data DTMb at 0.3 m spatial resolution (right) featuring terrain and buildings, and excluding high vegetation.

Figure 13. Rasterized point clouds classified into ground, and concrete manmade features (DTMb) at 0.3 m spatial resolution representing the Okponglo site.
Figure 14. Hydrological corrected elevation data DTMb at 0.3 m spatial resolution featuring terrain, buildings and boundary walls (upper) and classified point cloud data into terrain and manmade urban features (lower), both representing the Adenta site.
4.2 Orthomosaics of the urban areas surveyed by the UAV-imagery

Figure 15. Orthomosaics of the areas surveyed by the UAV-camera systems: Santa Maria (upper left); Legon Hall (upper right); Adenta (lower left); and Okponglo (lower right).
5. CONCLUSION

As a part of the Climaccess project activities, the testing of the UAV-based technical setup within the context of the rapidly urbanizing areas of Accra is seen as an opportunity to contribute to the development of the technical and methodological aspects of UAV applications which have the potential for significant applied usage in flood prediction and preparation as well as in urban planning in general.

In this report we described the main steps for generating high-resolution elevation data suitable for hydrologic modelling, and by using UAV-LiDAR and UAV imagery. The UAV-LiDAR derived DTMbs can be utilized as supplement to satellite or airborne-based data to optimize urban flood risk assessment at the local and city-wide scale. The potential of UAV-LiDAR systems to detect complex micro-topographic urban features that can be critical to water flow during floods can increase the level of detail of the projected flooded areas, securing the most precise and cost efficient drainage and flood protection in settlements exposed and vulnerable to the adverse effects of floods.

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