Inundation Mapping using UAVs: Fixed Wing vs. Multirotor

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SUMMARY

Accurate flood-risk mapping is critical for supporting emergency-response planning during a flood event, developing land use plans and regulations with regard to the construction of structures and infrastructures, and providing damage assessment in both spatial and temporal measurements. The technological development of Unmanned Aerial Vehicles (UAVs) has created a new tool for surveying and geospatial data collection. The advantage of UAVs, in comparison to traditional data acquisition approaches, is the ability to quickly deliver high spatial resolution imagery for a temporal event (e.g., the extent of flooding at a particular flood stage). They provide flexibility, enabling multiple sensor configuration including non-metric cameras and LiDAR sensors to detect a variety of potential data requirements. These advantages allow revisits (multiple flights), expedient emergency response planning and flood monitoring at a low cost affordable budget with enhancing overall safety on inundation areas. This research discusses the application of small UAVs, both multirotor and fixed wing, to produce survey grade geospatial products for flood mapping.

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1. UAV FOR FlOOD MAPPING

Accurate flood-risk mapping is creiticl for supporting emergency-response planning during a flood event, developing land use plans and regulations with regard to the construction of structures and infrastructures, and providing damage assessment in both spatial and temporal measurements. Over the past few years, North Carolina faces severe flooding conditions in the nation. For example, in October of 2016, Hurricane Matthew caused massive flooding in the eastern section of North Carolina, devastating towns such as Princeville, Lumberton, Smithfield, Kinston, and Goldsboro. During the Hurricane Matthew flooding, 17 dams failed causing additional flooding in low-lying areas. In the City of Smithfield, the water treatment plant was completely inundated, leaving the residents without potable water. In the towns of Princeville and Goldberg, low-lying residential and business areas were completely inundated. When the Neuse, Lumber, and Tar rivers went over their banks, hundreds of hog and poultry farms were flooded and remained underwater for several days, drowning several thousand hogs and millions of chickens and turkeys. These dead animals and their waste may have contaminated the groundwater for people who rely on wells and threaten the ecosystems of tidal estuaries and bays. A quick, low-cost approach is required to collect high-resolution survey and geospatial data that can be used for emergency-response planning, maintaining and designing infrastructure.

The recent development of the Unmanned Aerial Vehicles (UAVs) has created a new tool for geospatial data collection. The advantage of UAVs in comparison to traditional data acquisition approaches is the ability to quickly deliver high temporal and spatial resolution imagery in a wide geospatial extent. UAVs are flexible and can be flown with different sensors that can be configured to detect a variety of potential data requirements, especially for the areas with complex urban landscape as well as the inaccessible areas due to hazardous environments. Additionally, UAVs have lower cost with frequent revisit operations that are affordable and beneficial for monitoring and inspecting infrastructures. Unlike traditional surveys, the data collected either using traditional photogrammetric methods or with Lidar using UAV encompasses a complete data set that could be used for flood mapping and design and reconstruction of structures and infrastructures. In contrast, their short flight endurance, payload capacity, and small-scale coverage remain areas of weakness for their wide-scale implementation in flood mapping. The current advancements of UAVs (both fixed-wing and multi rotors) with the availability of sophisticated computer vision, robotics, and geomatics techniques allow a centimeter-level resolution and accuracy data generated with low-cost digital cameras (Colmina and Molina, 2014). UAVs have been applied successfully for various applications, including for ecological (Mulero-Pázmány et al., 2015), topographical studies (Gonçalves and Hernriques 2015), geomorphology and hydrology (Ouédraogo et al., 2014, Stöcker et al., 2015), geological survey (Tziavou et al., 2018), agriclture (Yinka-Banjo et al., 2019; Hashemi-Beni et., 2020), landslide (Rossi et al., 2018), and flood management (Hashemi-Beni et., 2018; Gebrehiwot et al., 2019; Gebrehiwot et al., 2020).

2. UAV MAPPING

2.1 Flight Planning

A conceptual design for mapping workflow processes is developed for data acquisition using UAV. This includes development of the flight plan model for the area of interest, establishment of appropriate ground control points and check points for geo-referencing of low-altitude photogrammetric measurements and evaluation the results. Waypoints for image acquisition based on the desired ground resolution, amount of image overlap, and area to be surveyed is calculated prior to the data collection. Depending on the mapping application, the value for flight planning parameters can be different. For example, maximizing photographic overlap, especially forward overlap is crucial for minimizing canopy height error and overall sampling of the forest canopy (Dandois et al. 2015). Also it should be noted that according to regulations, the UAV should be visible throughout the entire flight and observe the surrounding airspace for other traffic or hazards. The remote pilot should determine the maximum distance that the UAV can be flown away at the lowest flying height in a study area.

2.2 Georeferencing

Georeferencing is a critical step in UAV mapping and ultimately impact the accuracy of results. A minimum of three Ground Control Points (GCPs) is required to transfer the results into a desired coordinate system through the indirect georeferencing process, however, it is well known that increasing the number of GCPs will lead to a higher accuracy of the final results. Oniga et al. (2020) investigated the suitable number of GCPs to derive high precision results and what is the effect of GCPs systematic or stratified random distribution on the accuracy of the georeferencing process and the final products, respectively. They found GCPs in the corners are essential, but should be placed not too far out in the corners of the area of interest. Placing GCPs along the border of the block is not optimal, and interior control points are improving the accuracy significantly and a stratified random placement of control points offers a similar accuracy and an even better one than a systematic placement. Although an increase in the number of GCPs leads to improved accuracy, for higher number of GCPs that optimal number, the improvements are only marginal. The research obtained an accuracy of 3 GSD in planimetry and 7 GSD in elevation over a surface of approximately 4000 m^2 using 20 GCPs. It should be noted that the characteristics of the study area, the flight design, and the suitable number of GCPs are important factors affecting the results accuracy, and extrapolating beyond the area enclosed by control points it leads to lower accuracy, also if a very high number of control points is needed. Note that acquiring flood images using the Real-Time Kinematic Global Navigation Satellite System (RTK-GNSS) mounted UAV or post-processing kinematic (PPK) technology can improve georeferencing accuracy in the photogrammetry process (Forlani et al., 2018).

2.3 UAV Data Processing

Structure from Motion photogrammetry (SfM) is the most used technique for UAV image processing. SfM methods require multiple overlapping images and use feature-based image matching methods for image-to-image registration and 3D surface construction. The 3D point cloud created using SfM approaches is unclassified and 3D point cloud classification is a crucial step to group water points, reconstruct 3D water surface, and extract meaningful information from the inundation areas. However, the classification is very challenging due to irregular geometric attributes and highly noisy and nonuniform sampling of point cloud data. A recent study (Gebrehiwot et al., 2021) addressed this issue by using a deep learning-based approach. Deep learning is a machine learning class where artificial neural networks, algorithms inspired by the human brain, learn from big data. Similarly, to how we learn from experience, this algorithm would perform a task repeatedly, each time tweaking it a little to improve the result. Convolutional Neural Network (CNN), a class of deep learning commonly applied to imagery, provides a hierarchical representation of the data using various convolutions and can automatically extract and learn feature representation directly from big datasets. This allows more extensive learning capabilities and, thus, higher performance and precision.

3. UAV MAPPING: FIXED WING or MILTIROTORS

When employing UAV for mapping purposes, the main question is, “what kind of UAV should be used?” It is a critical question because the data gathered will only be as good as the type of UAV can provide. A variety of UAVs, fixed-wing or multi-rotor, are available with their advantages and disadvantages. Multi-rotors are easy to fly, takeoff including landing, and can efficiently perform autonomous flights (Thamm et al., 2015). However, their flight time capability and coverage area are the main limitations (Cai et al., 2014). On the other hand, fixed-wing UAVs can cover large areas in one flight and have better flight endurance. But they require a suitable landing area, including skill by the pilot to land them safely to avoid damage to the sensors and craft. Boon et al. (2017) investigated the terrain modeling quality for an environmental study in South Africa using multirotor and fixed-wing UAV. They found that the multi-rotor performed well providing vegetation representation, erosion gully representation, wetland slope mapping, and contour mapping, while the fixed-wing performed well providing wetland slope mapping and contour mapping. The fixed-wing had a longer flight time, better georeferencing, better cost, and simpler maintenance. The multi-rotor had a better payload and better stabilization. Overall, the multi-rotor data was more accurate and better-represented environmental features. Nevertheless, the basic identification and estimation impacts from the fixed-wing data was still satisfactory (Boon et al. 2017).

Geomatics (land surveying, remote sensing and photogrammetry) is a profession striving to provide high quality, accurate, 2D and 3D data of the world around us. The integration of UAV provides significant advantages in mobility, deployment, and ease of obtaining data. It is becoming much easier to employ UAVs to collect high quality video and imagery which can be used for countless applications. Mapping for flood management is one sector that can benefit greatly from the advances of UAV. Understanding the limitations of this technology is just as important as knowing the benefits. For surveying applications certain UAV and software much be utilized. Large areas that do not require highly accurate data will be best served by a fixed wing. Smaller sites that need highly accurate, possibly multi-sensor, outputs may result best from a multi-rotor. Multi-rotor is more stable in adverse weather and is typically much easier to deploy. Multi-rotor can take off and gain appropriate altitude within the footprint of takeoff making it good for tight quarter take offs. For checking damage of large areas for initial investigation a fixed wing would be a very good candidate.

Obtaining images during floods can pose difficulties such as wind and weather. The typical UAV flown for this application cannot handle heavy rain and wind. Battery life is another consideration. Most UAVs have an approximate flight times of 30 minutes +/-. This means that takeoff and landing may occur in the flooded areas. Typical photogrammetry practices do not produce good results with heavy tree cover or water covering. The images need key points for the software to match together. If there is no ground to see a Dense Earth Model (DEM) may not be possible.

Employing best practices and pre-planning can mitigate many of these challenges. Data processing methods will struggle with large areas of heavy tree cover and large areas of water. Consider trying to create flight plans that utilize unique objects just as the ground, buildings, and roads. This will help significantly with image matching. Best practices for flood areas include placing GCP's during the flood time so that GCP's are verifiable visible. If placing GCP's is not viable during a flood event, then the use of RTK UAVs can be implemented. These units will provide accurate models of flooded areas without the need for GCP's; however, independent surveyed points of features visible in the imagery obtained at a higher surveyed accuracy should be utilized to test the developed models.

GCP's are a necessity for quality 3D modeling. These must be placed on the ground prior to the flight. If an area is flooded it may cover GCP's or prove difficulty to locate areas suitable for GCP's. Significant areas may be inaccessible and as a result unusable to place GCP's. Poorly placed GCP's limit the ability of the georeferencing to position the point cloud within a spatial coordinate system. This then affects any calculations performed based upon the models derived from the point cloud. Improvement in direct georeferencing methods such as RTK UAV suggests that GCP-free UAV photogrammetry has great potential in the future. Verifying that the data obtained is accurate through independent quality control survey points is just as important as the data collected. Depending on desired output checks could include elevation spot checks, 2D checks, water height both elevation and location.

When it comes to surveying and mapping accuracy and precision are key. This must remain true as we begin to integrate new technology into our workflows. Not every UAV is suitable nor is every camera. Creating quality flight plans, including sufficient control, and knowing the limitations of this technology and the system you have chosen to use before performing a mission. This study is an attempt to provide some research insight for these tough questions.

During the conference we will present the results of UAV flood mapping using both fixed-wing and multi-rotor over The Tarboro Wastewater Treatment Plant, which is located along the Tarboro River in North Carolina, US.

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